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Bioremediation Treatability Study for Remedial Action at Popile, Inc., Site, El Dorado, Arkansas

Phase II. Pilot-Scale Evaluation

Lance Hansen, Catherine Nestler, Michael Channell, David Ringelberg, Herb Fredrickson, Scott Waisner

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Preface

The work reported herein was conducted for the U.S. Army Engineer District, New Orleans (USAEDNO). Funding for this project was provided through the USAEDNO by U.S. Environmental Protection Agency (EPA), Region 6.

This report is the second in a multiphase project. The first report , "Land farming bioremediation treatability studies for the Popile, Inc., Site, El Dorado, Arkansas," detailed a study conducted to evaluate contaminant degradation at a microcosm-scale level. This report details work conducted to evaluate design information applicable to the full-scale remediation of the process area soil from the Popile site.

This report was prepared by Messrs. Lance Hansen, Michael Channell, David Ringelberg, and Scott Waisner, Dr. Herb Frederickson, and Ms. Catherine Nestler, Environmental Restoration Branch (ERB), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Chemical analyses were performed by the Environmental Chemistry Branch, ERDC. Physical analyses were performed by the Geotechnical Laboratory, ERDC. We gratefully acknowledge the special assistance provided by Messrs. Karl Konecny and Fred Ragan, EL, sampling assistance provided by Messrs. Demetrick Banks and Samuel Tucker, and Ms. Lynn Vaughn, EL, as well as the participation of students of the Science and Engineering Apprentice Program, George Washington University.

This study was conducted at ERDC under the direct supervision of Mr. Daniel E. Averett, Chief, ERB, and Mr. Norman R. Francingues, Chief, Environmental Engineering Division, and under the general supervision of Dr. John Keeley, Director, EL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James S. Weller, EN, was Commander.

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1 Introduction

Site History

The Popile, Inc., site is a former wood-treatment facility located in El Dorado, AR. The primary contaminants found at the site include pentachlorophenol (PCP) and creosote compounds associated with wood treatment, including polycyclic aromatic hydrocarbons (PAH). The site was purchased by Popile, Inc. Wood-treatment operations ceased in July 1982. In 1984, Popile consolidated three impoundment ponds into one. This closure activity was administered by the Arkansas Department of Pollution Control and Ecology. In 1988 and 1989, an Environmental Protection Agency (EPA) field investigation revealed contaminated soils, sludges, and groundwater at the site. EPA determined that an emergency removal action was necessary. This was conducted from September 1990 to August 1991. The emergency action consisted of modifying the site drainage, placing and seeding topsoil, and solidifying and placing sludges into an onsite, soil-holding cell.

The EPA's design contractor, Camp, Dresser and McKee, Federal Programs, was tasked with the development of the Remedial Investigation/Feasibility Study for the Popile site. The remedy that was approved involves the excavation and treatment of approximately 126,142.5 cu m (165,000 cu yd) of contaminated soils and sludges in onsite land treatment units (LTUs). Indigenous microorganisms were expected to break down the target contaminants to less harmful and less mobile constituents.

Two types of contaminated soils exist on the site. The first is the soil-holding-cell material, consisting of soils stabilized with rice hulls and fly ash (pH approximately 10) under previous emergency remedial activities. The second is the process area which consists of soils that were contaminated by spills, leaks, and open air drying during wood-treatment activities. Results of Phase I indicated it unlikely that material from the soil cell could be successfully treated using landfarming techniques. Therefore, the Phase II evaluation was conducted on contaminated material only from the process area.

Objectives of Study

The objectives of the Phase II study were to:

a. Determine if the treatment goals specified in the Record of Decision (ROD) are achievable for the process area soil through land farming technology (these goals are: 5 ppm benzo(a)pyrene (BaP) equivalents and 3 ppm PCP).

b. Evaluate the contaminant degradation kinetics associated with the landfarming treatment.

c. Evaluate the leaching potential of the treated soil.

2 Literature Review

Contaminants of Interest

Pentachlorophenol (PCP)

Because of its potency as a biocide and its persistence in the environment, PCP has been widely used as an insecticide, fungicide, and disinfectant. It's now a restricted-use pesticide, and although it's no longer available for residential use, PCP is still a common component of industrial wood preservative for power line poles, railroad ties, and fence posts (Appendix A). PCP is not a particularly volatile chemical. It will undergo photolysis, especially in surface water. It is relatively hydrophobic and tends to adsorb onto soil particles, but the strength of the bond depends on the pH of the soil. At lower pH, it may dissociate into the water, leaching through contaminated soil and entering the groundwater in that manner. PCP and several of its breakdown intermediates (i.e., tetrachloro-*p*-hydroquinone) are considered possible carcinogens (ATSDR 1994).

Polycyclic aromatic hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons are multiringed, organic compounds, characteristically nonpolar, neutral, and hydrophobic. PAHs have two or more fused benzene rings in a linear, stepped, or cluster arrangement (Appendix A). PAHs occur naturally as components of incompletely burned fossil fuels and they are also manufactured. A few of these are used in medicines, dyes, and pesticides, but most are found in coal tar, roofing tar, and creosote, a commonly used wood preservative. The Popile site is contaminated with high concentrations of a wide range of PAHs, including the recalcitrant, higher molecular weight PAHs. Some lower molecular weight PAHs are volatile, readily evaporating into the air. Others will undergo photolysis. Because they are hydrophobic and neutral in charge, PAHs are strongly adsorbed into soil particles, especially clays. Park et al. (1990) studied the degradation of 14 PAHs in two soils. They found air-phase transfer (volatilization) an important means of contaminant reduction only for naphthalene and 1-methylnaphthalene (the two-ring compounds). Abiotic mechanisms accounted for up to 20% of the total reduction, but only involved two- and three-ring compounds. Biotic mechanisms handled reduction of PAHs over three-ring compounds. The persistence of PAHs in the environment, coupled with their hydrophobicity, gives them a high

potential for bioaccumulation. PAHs are considered to be both mutagenic and carcinogenic (ATSDR 1995).

Benzo(a)pyrene (BaP) equivalents

Different PAHs each have different toxic potencies that vary widely. Some PAHs appear to be nontoxic, while others have been classified as probable or possible carcinogens. BaP is often used as an indicator for risk assessment of human exposure, because it is highly carcinogenic, persistent in the environment, and is toxicologically well understood. This level of knowledge doesn't exist for most of the other PAH compounds.

Because PAHs generally occur in mixtures, toxic equivalency factors (TEF) were proposed. These factors were similar to those used in the risk assessment of mixtures of polychlorinated biphenyls (PCB). The U.S. Environmental Protection Agency (USEPA) took the first step in 1984 by separating the PAHs into carcinogenic and noncarcinogenic compounds. All of the PAHs were rated, using BaP as a reference and giving it a value of 1.00. However, this method led to an overestimation of exposure risk since the carcinogenicity of the compounds was unknown. In an attempt to overcome this liability, Nisbet and LaGoy (1992) developed a new method based on the response of the compounds while testing one, or more, PAHs concurrently with BaP in the same assay system (usually lung or skin cell carcinoma). BaP remained the reference carcinogen assigned the value of 1.00. Sixteen other PAHs were ranked in comparison to BaP carcinogenicity.

This system was tested by Petry, Schmid, and Shlatter (1996) who assessed the health risk of PAHs to coke plant workers. There are drawbacks to any system that uses equivalency factors. The uncertainties in this case arise primarily from dealing with inconsistent mixtures. Carcinogenic potency could be affected by differences in bioavailability, a competition for binding sites, co-carcinogenic action, or the effects of metabolism. Nevertheless, Petry and his co-workers found that the BaP equivalents developed by Nisbet and LaGoy were valid markers for PAH health risk assessment.

Environmental risk assessment, in a slight contrast to human health risk, looks at the PAHs that usually occur in contaminated environmental systems and that have the highest TEFs (by the Nisbet and LaGoy system). This gives seven PAHs, listed in Table 1, with the highest environmental risk: benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene. Because BaP was stipulated in the ROD, this method was used to evaluate the effectiveness of contaminant degradation.

Table 1 Toxic Equivalency Factors (TEFs) for Environmental PAHs		
Compound (abbreviation)		**TEF (after Nisbet and LaGoy 1992)**
Benzo(a)anthracene	(BAANTHR)	0.1
Chrysene	(CHRYSE)	0.01
Benzo(b)fluoranthene	(BBFLANT)	0.1
Benzo(k)fluoranthene	(BKFLANT)	0.1
Benzo(a)pyrene	(BAP)	1.0
Indeno(1,2,3-c,d)pyrene	(I123PYR)	0.1
Dibenzo(a,h,)anthracene	(DBAHANT)	1.0

Landfarming

According to the Federal Remediation Technologies Roundtable (1998), there are several EPA-accepted processess to remediate the waste from wood-treatment sites. These treatment technologies include thermal desorption, incineration, landfarming, and bioremediation. The choice of remediation technology is based on the concentration of the contaminants, cost, intended use of the land after remediation, and other factors. With the current "land ban" on hazardous waste disposal and the restrictive regulations on incineration, landfarming as a way of treating waste has become increasingly attractive (USEPA 1995) and was selected as the technology to remediate the Popile site.

Generally, during landfarming, the degradation process will destroy the organic contaminants in place without the high cost of excavation and material handling. The release of volatile contaminants into the air is minimized. The site is monitored on a continuous basis so the potential for hazardous waste leakage is reduced. The costs associated with landfarming are generally much lower than ex situ treatment alternatives. In most instances, the treatment is accepted by the community and the site can be put to other uses when the treatment is complete (USEPA 1995). This last point has become increasingly important in the 1990's with the EPA Superfund policy changes towards "brownfields" development.

Successful bioremediation through landfarming has to meet these three criteria:

a. There must be a loss of the contaminant over time.

b. There must be a demonstrated ability of the indigenous microorganisms to degrade the contaminant over time.

c. There must be evidence that this biodegradation potential is expressed in the field.

Landfarming technology remediates contaminated soil in an aboveground system using conventional soil mangement practices. The contaminant is converted to a less toxic or nontoxic form either abiotically (ex. photolysis) or biotically, through the metabolism of the indigenous microbial population

(Golueke and Diaz 1989, Harmsen 1991). Landfarming as a form of applied bioremediation is the cultivation of contaminated soil at properly engineered sites to stimulate the naturally ocurring microorganisms to degrade the organic contaminants. The landfarming operational goal, then, is to manage the parameters that optimize conditions for microbial activity. Typically, these include the soil carbon to nitrogen ratio, soil moisture, pH and oxygen content, temperature and cultivation frequency. The type of soil being remediated, and the type and concentration of contaminant, are also factors that shape landfarming management. The rate of biodegradation can be monitored through the rate of CO_2 production and release and by chemical analysis of the hydrocarbons (King 1992, Reisinger 1995).

When weighing treatment options, however, the disadvantages of landfarming must be considered. It is land and management intensive. An improperly designed system could lead to adverse environmental effects such as groundwater contamination. Air and odor emissions may also be hazardous, or simply a nuisance. Airborne particles could be a problem. Finally, landfarming is not suitable for all kinds of hazardous wastes (e.g., radioactive wastes).

Because landfarming involves a biological system, the limits to this biological system are also limits to landfarming. The bacteria found most often associated with successful landfarming are either obligate or facultative aerobes, therefore the soil oxygen content is an important parameter. The tilling (cultivation) frequency is an important aspect of maintaining the oxygen level as well as exposing the bacteria to renewed sources of the contaminant. Most of the microbial communities involved with landfarming are mesophilic. The pH range that will support their growth is relatively narrow, usually in the 6.0 to 7.5 range. They prefer a moisture level that is 30 to 90 percent of the water-holding capacity of the soil. Also, most hazardous wastes are nutrient deficient. Some kinds of wastes are lethal (heavy metals), or inhibitory (in high concentrations) to the microbial communities. The degradation process should be studied in the laboratory to determine that it doesn't produce intermediates or end products that are as harmful as the contaminants being remediated. However, all of these limitations to landfarming can be overcome, with the exception of the presence of heavy metals and/or radioisotopes in the contaminant mixture (Golueke and Diaz 1989, USEPA 1995).

Landfarming of soils contaminated with PAHs and PCP has been studied several times but not usually at the concentrations found at the Popile site. The GRACE Daramend™ SITE evaluation report (USEPA 1996) cites initial concentrations of 352 mg/kg total of chlorinated phenols (TCP) and 1,710 mg/kg of total PAH reduced in 254 days to 43mg/kg and 98 mg/kg, respectively. Clark and Michael (1996) used "enhanced" landfarming to achieve degradation goals in 15 months. The study of "aged" PCP (McGinnis et al. 1994) found that concentrations up to 300 mg/kg weren't inhibitory to the bacteria if soil phosphorus and oxygen concentration levels were maintained. Hurst et al. (1997) have found microbial activity in soil containing up to 500 mg/kg PCP. Again, the oxygen concentration in the soil was a significant factor in successful degradation, although anaerobic degradation of PCP has been reported (Frisbie and Nies 1997).

3 Experimental Design

Land Treatment Units

LTU Design

The pilot-scale LTUs were built to simulate the full-scale LTU design being implemented onsite at Popile. The pilot-study LTU consisted of a bottom impermeable liner, a sand bed leachate collection system, and hard standing walls to withstand impact from cultivation. To provide environmental security for this study, a secondary containment cell was constructed similar in concept to a landfill liner (modified American Society for Testing and Materials (ASTM) D-1973-91 (ASTM 1991)). This secondary system was backfilled with clean sand to provide a base for the LTUs. Figure 1 illustrates the design of the primary and secondary containment systems and the leachate collection system. Actual construction is shown in Figures 2 and 3 in Materials and Methods (Chapter 4).

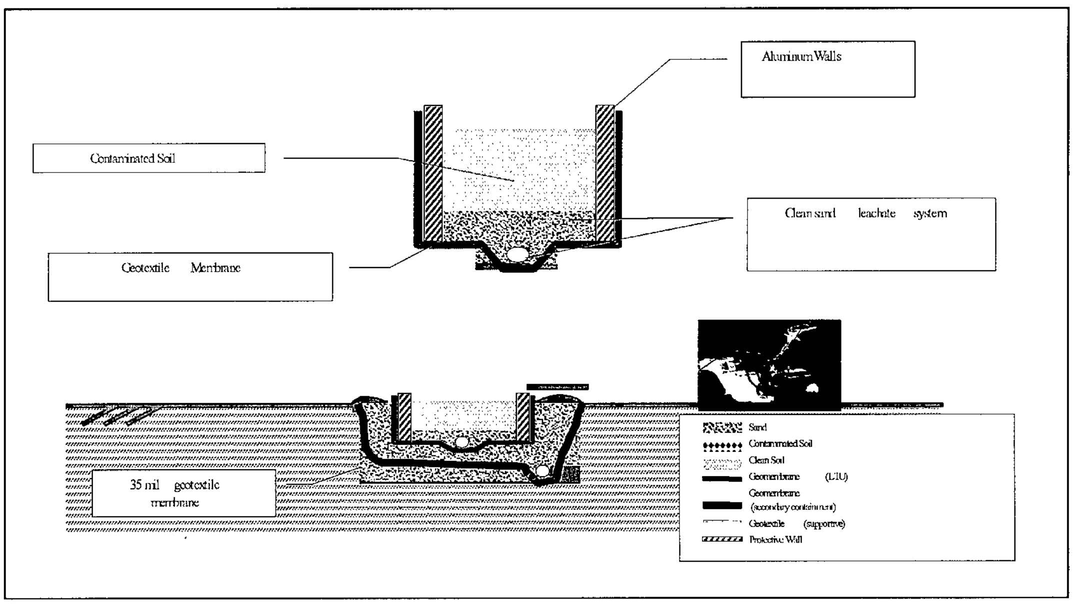

Figure 1. Design of primary and secondary containment systems

Experimental design

The study was designed to evaluate two cultivation management strategies. LTU 1 was cultivated on an oxygen dependent basis. When the oxygen concentration in the pore space was reduced to 5 percent, the lift was to be tilled. LTU 2 was cultivated on a fixed schedule, every 2 weeks, independent of the oxygen concentration.

Soil samples were taken every 2 weeks. The parameters included in the bimonthly soil analysis were contaminant concentration, nutrient concentration (total Kjeldahl nitrogen (TKN), total phosphate (TP)), total organic carbon (TOC), pH, and moisture content. Microbial biomass was evaluated intermittently throughout the study. At the initial and final sampling events, leachability, particle size distribution (PSD) and Atterberg limit tests were performed. At the initial sampling only, metal concentrations and total volatile solids were examined. The analysis schedule is shown in Table 2.

Table 2
Sample Analysis Plan

Initial	2-week Intervals	Final
PCP concentration	PCP concentration	PCP concentration
PAH concentration	PAH concentration	PAH concentration
Nutrient and TOC concentration	Nutrient and TOC concentration	Nutrient and TOC concentration
pH	pH	pH
Moisture content	Moisture content	Moisture content
Leachability		Leachability
Microbial biomass		Microbial biomass
PSD		PSD
Atterberg limits		Atterberg limits
Metals		
Total volatile solids		

Metabolic Analysis

Respiration, measured by soil gas analysis, was monitored twice each week to record changes in the oxygen and carbon dioxide concentrations.

Microbial characterization of the indigenous microbiota was conducted to assess the biomass and community composition in each LTU. This analysis was performed on contaminated soil before the LTUs were loaded, soil after it was transferred to the two LTUs (Day 0), and intermittently throughout the study on Days 14, 42, 84, 126 and 168.

Abbreviations

This report uses standard abbreviations for the PAHs and analytical chemistry. The PAHs and PCP are listed in Appendix A with full name, abbreviation, and chemical structure.

4 Materials and Methods

LTU Construction

Secondary containment system

A backhoe was used to excavate a pit measuring approximately 9.14 × 9.14 × 0.91 m (30 × 30 × 3 ft). It was subdivided into two sections using a row of sandbags. One side of the pit area was used for the LTUs and the other side for the leachate collection containers. The 36-mil liner, used for both sides of the pit, was molded into the corners, over the divider, and extended beyond the edge of the pit (Figure 2). The Cooley Coolguard® secondary containment liner was purchased from Colorado Lining, International.

A leachate collection system consisting of 10.2-cm (4-in.-) diameter perforated PVC pipe was placed on top of the liner and connected to a sump. This system was similar for both sides of the pit. A ½-hp sump pump was installed in each sump to move the leachate into the storage container. Next, 25.4 cm (10 in.) of washed gravel was placed in each side. A geotextile fabric was placed on top of the gravel to keep sand from filtering down and plugging up the leachate collection system. The half of the pit that supports the tanks was filled with sand and covered with another layer of the geotextile.

Primary containment system and LTUs

The primary containment leachate collection system also employed the 36-mil Cooley Coolguard® liner and standard ½-hp sump pumps. The LTU walls and bottom were constructed from 0.64-cm- (¼-in.-) thick aluminum sheets. Sandbags were used as structural supports, separating the two containment areas.

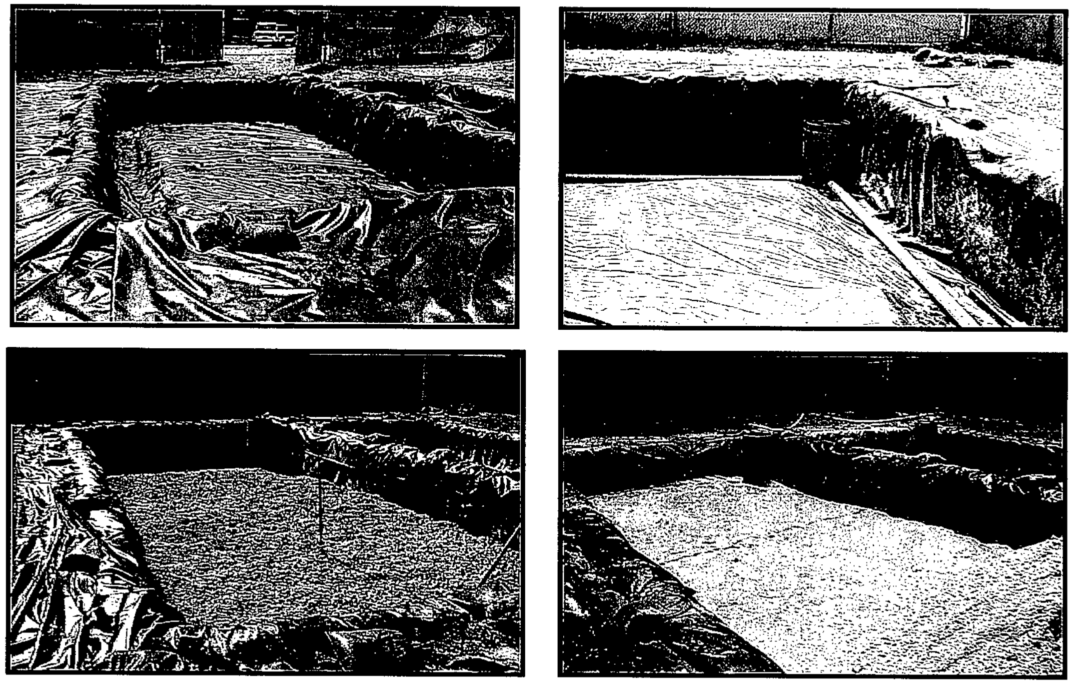

Figure 2. Construction of the secondary containment system

A stable base for the LTUs was formed in the second half of the pit by filling it about halfway with sand. Two sheets of aluminum 1.22 × 3.05 m (4 × 10 ft) were used for each LTU (6.10 m (20 ft) total length). The aluminum had 1.27 cm (½-in.) holes drilled on 15.24-cm (6-in.) centers to allow for drainage of water from the LTU. Sandbags were used to form the support walls for the LTUs. With the walls in place, the aluminum sheets were removed and replaced with more of the 36-mil containment liner. A sump was installed at each end of the LTU with 10.16-cm (4-in.) perforated PVC pipe connected to the sump. Gravel was again placed over the leachate collection system and covered with geotextile. The bottom sheets of aluminum were replaced in each LTU and preformed aluminum walls were positioned against the sandbags to make the sides. The last step was to fill in the area around the outside of the LTUs with sand. Each completed LTU was approximately 45.72 cm deep, 1 m wide, and 6 m long (18 in. deep, 4 ft wide, and 20 ft long) (Figure 3).

Rainfall at the pilot site was monitored electronically with a Rainwise ® tipping bucket. In addition, a direct-reading rain gauge served as backup.

Water that leached through the LTUs was contained onsite and tested for presence of the contaminants on Day 14 and again on Day 168. Chemical analysis of the leachate was performed by the Environmental Chemistry Branch, U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Contaminated water was treated by carbon filtration, retested and disposed of by ERDC.

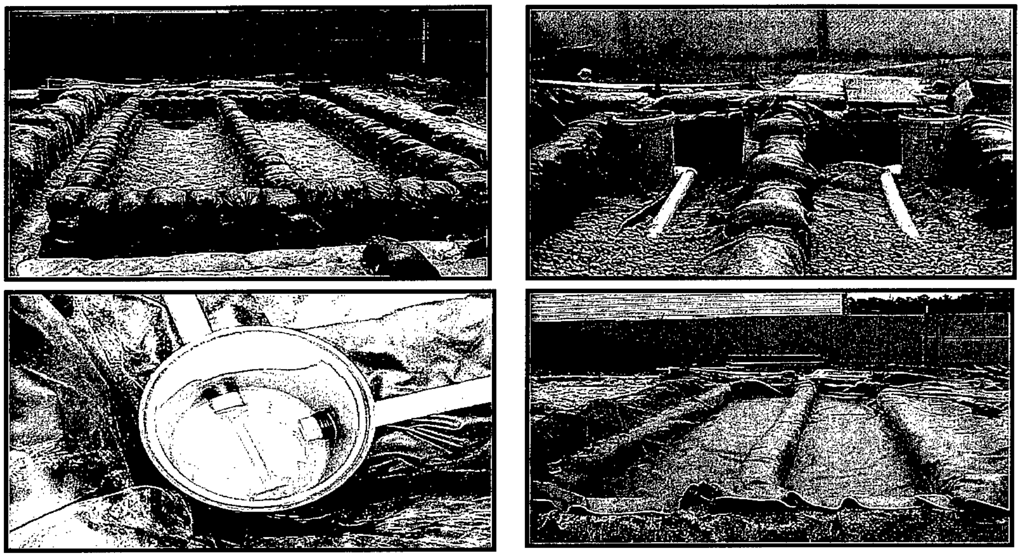

Figure 3. Construction of primary containment system and LTUs

Sample Collection

Soil sample collection

As shown in Figure 4, each LTU was subdivided into 20 sections, each one 0.61- × 0.61-m (2-ft × 2-ft). These were lettered "A" through "T". A sampling grid was constructed from a 0.61- × 0.61-m (2- × 2-ft) section of plexiglass drilled with 36 equidistant holes for the soil corer. At each sampling interval, five randomly located cores were collected from each of the 20 sections. The five soil cores for each single grid were combined in a 950-cc amber jar and manually homogenized into a single sample. A random number generating computer program selected 7 of these 20 grids for analysis. The remaining 13 samples were archived at 4 °C in their original collection jar. The stainless steel corer (1.91 × 48.26 cm (3/4 × 19 in.)) was purchased from Forestry Suppliers, Inc.

Respiration analysis

Dry wells, installed in each LTU for respiration analysis, were designed at WES and made by PSI, Inc., Jackson, MS. They were constructed from a 15.24-cm (6-in.) upper ring and cap of PVC superimposed on a 30.48-cm (12-in.) vertical dry well made of standard 5.08-cm (2-in.) slotted PVC (Figure 5). The cap was equipped with a three-way plastic stopcock purchased from Cole-Parmer®.

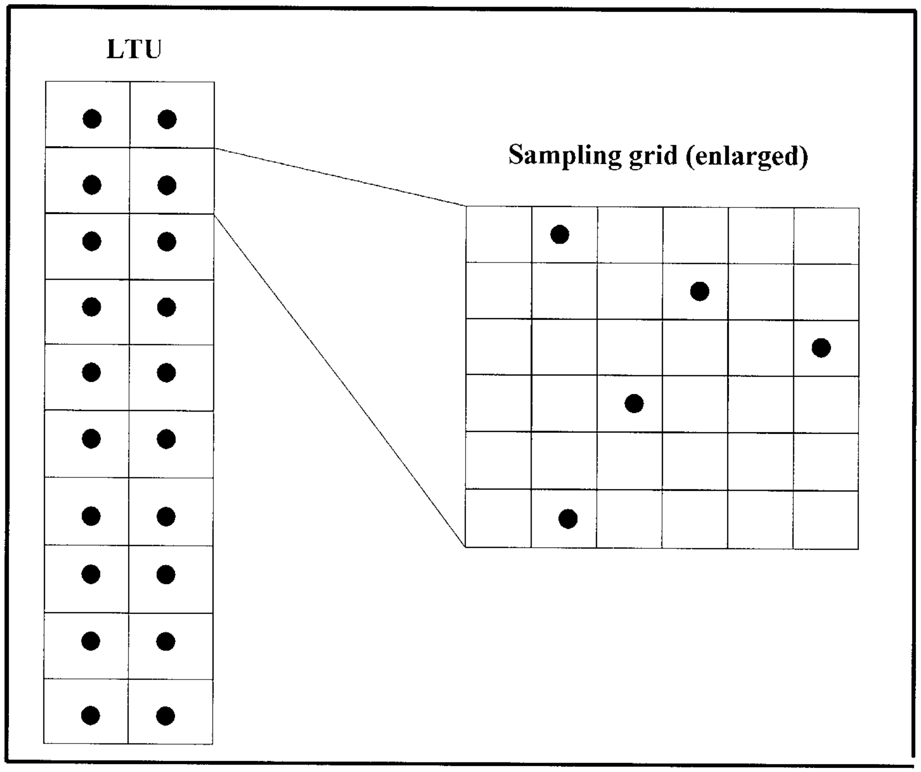

Figure 4. LTU random sampling grid

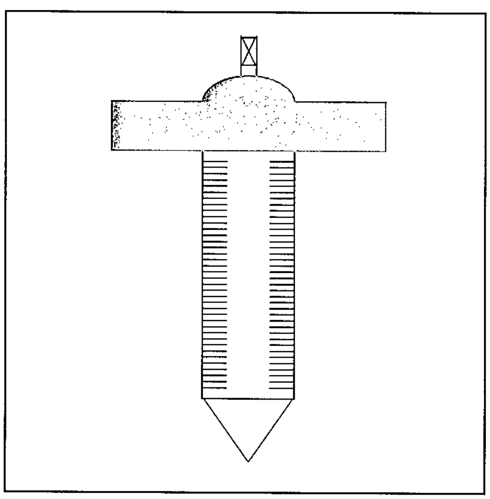

Figure 5. Conceptual dry well design

Cultivation

LTU 2, only, was tilled after soil sampling. When necessary, water and/or nutrients were added to the unit prior to tilling. The surface of LTU 1 was raked lightly after sampling, to fill in the sample holes. LTU 2 was cultivated to a depth of 30.48 cm (12 in.) with a rear-tine rotary cultivator.

Sample Analysis

Physical analysis

Atterberg limit analysis and particle size distribution (PSD) were used to evaluate the physical structure of both the untreated and treated soils. The Atterberg limit test was performed by the Geotechnical Laboratory, ERDC, according to Corps of Engineers laboratory testing manual standard procedures. Particle size distribution was measured on a Coulter LS100Q particle counter according to instrument protocol. Soil moisture was analyzed on a Denver Instrument IR-100 moisture analyzer and validated by oven- drying at 105 °C for 24 hr.

Leachability

Two leachability tests were conducted, the sequential batch leaching test (SBLT) and the synthetic precipitate leaching procedure (SPLP). The SBLT consists of four repeat extractions of the same sample using distilled-deionized water in a 4:1 (water:soil) ratio. The slurry is tumbled for 24 hr, centrifuged, filtered, and the water fraction analyzed for the contaminants. The SPLP was performed according to SW846, EPA Method 1312, and consists of a single extraction using a dilute acid solution. Maximum extractant concentration for a known solid-phase concentration is controlled by equilibrium partitioning. This can be determined from the single-point analyses in the SPLP or the SBLT. The SBLT is thought to be more aggresive due to the fact that the water has no ions in it and is looking to absorb ions and come to equilibrium with the sample. This information is useful and has regulatory acceptance, however it is incomplete because it precludes analysis of residual contaminant in the solid matrix which may be eluted under repeated or changing equilibrium conditions such as are observed in repeat rain events. To comply with necessary regulatory requirements and meet the needs of the project sponsor, both leachability tests were conducted with five replicates at Day 14 and Day 168.

Chemical analysis

Contaminant concentrations, metals, nitrogen, phophate, and total organic carbon analyses were performed by the Environmental Chemistry Branch, ERDC, on both treated and untreated soil. PAH and PCP concentrations were determined using SW846 EPA Method 8270c for gas chromatography/mass spectrometry (GC/MS) after extraction by Method 3540c. Total organic carbon samples were analyzed on a Zellweger Analytic TOC analyzer, according to instrument specifications. The nitrogen and phosphate analysis was performed using the Lachat 8000 Flow Injection Analyzer (FIA). The preparation methods were modified versions of EPA-600/4-79-020 (1983 revision), 365.1 and 351.2, respectively. Metals and total volatile solids were determined according to standard methods (SW 846). Soil pH was determined for a soil-distilled water slurry (1:1, wt/vol) using a Cole-Parmer® pH meter.

Metabolic analysis

Gas analysis in the landfarming units was accomplished using an LMSx Multigas Analyzer® from Columbus Instruments. Oxygen, carbon dioxide, and methane concentrations in the soil were monitored. The drywells were labeled and centered in each LTU grid section. Following gas sampling, the drywells were lifted from LTU 2, soil samples were taken, the soil was tilled, and the drywells were reinserted in the appropriate section. The drywells remained in place in LTU 1.

Microbial biomass was determined at Days 0, 14, 42, 84, 126, and 168 during the study. Two grams (wet weight) of soil /sample were subjected to an organic solvent extraction to quantitatively recover bacterial membrane lipid biomarkers (ester-linked phospholipid fatty acids or PLFA) as outlined by White and Ringelberg (1998).

Data Analysis

Chemical data

The chemical analytical data were reduced to develop average sums of the concentrations of total PAH, individual PAH compounds, and total PCP. To calculate the magnitude of reduction and the rate of degradation of these contaminants, the initial and final concentration values were used. Zero order (concentration independent) removal rates were assumed due to the high concentrations of the contaminants (Shane 1994). Contaminant concentration and physical data values are significant (n = 7) at the 95% confidence level.

The total % PAH and total % PCP reductions were calculated using Equation 1:

$$\% R_{contaminant} = ([C_{initial}] - [C_{final}]) / [C_{initial}] \times 100 \qquad (1)$$

where

$\%R_{contaminant}$ = removal of contaminant, % of initial

$[C_{initial}]$ = average initial contaminant concentration in the LTU

$[C_{final}]$ = average final contaminant concentration in the LTU

The rate of elimination (k) of the contaminants was calculated as a concentration-dependent, zero-order reaction

$$k = - dC/dt \qquad (2)$$

$$k = -(C_1 - C_2)/(t_2 - t_1) \qquad (3)$$

where

$k =$ concentration change / time

$C_1 =$ concentration at Day 0

$C_2 =$ concentration at Day 168

$t_1 = 0$

$t_2 = 168$

The time required to acheive the ROD goals can be calculated by substituting the goal (5 ppm for PAH) for the final concentration(C_2), and solving for "t_2."

Because $t_1 = 0$, this simplifies to,

$$T_2 = (C_2 - C_1)/k \tag{4}$$

Microbiological data

The microbiological data was subjected to a Tukey hierarchal significant difference (HSD) to determine if there was a significance to the differences between the data for the two LTUs, taking into account that more than two samples were taken (Ringelberg et al. 1989). The hierarchal cluster analysis was used because there was no *a priori* hypothesis tested. It attempts to minimize the the sum of squares of any two clusters found at each step of an algorithim. It was used to try to determine if a significant relationship existed between sets of data for the two LTUs (Ringelberg et al. 1997).

5 Results and Discussion

Physical Characteristics of the Popile Soil

Atterberg limits

The Atterberg limits, Table 3, are the values where the moisture content of the soil will allow the soil to change state from a solid to a semisolid, to a plastic, and then a liquid. These limits also establish the soil type. LTU 1 initially had a liquid limit of 23% and a plastic limit of 17%. The soil type was designated clay/clay-silt. LTU 2 demonstrated a liquid limit of 26%, a plastic limit of 17%, and was designated per Corps of Engineers classification as a clay soil.

Table 3
Atterberg Limits

	LTU 1		LTU 2	
Characteristic	**Day 0**	**Day 168**	**Day 0**	**Day 168**
Liquid limit	23	24	26	23
Plastic limit	17	19	17	19
Plasticity index	6	5	10	4
Soil type	clay/silt	silt	clay	silt

Particle size distribution (PSD)

The initial PSD supported the results of the initial Atterberg limits (Appendix B). Based on the Corps of Engineers particle size classification, soil typ is indicated by the Atterberg Limits. The text indicates that the same conclusion for soil classification is achieved by both methods: LTU 1 consisted of 68% fines (clay/silt), and LTU 2 consisted of 76% fines (Figure 6). At Day 168, these values were not significantly different.

Dust is a drawback to landfarming that can be countered by keeping the soil surface moist or covered, for example with plants. Dust production results in a loss of fines, the clay/silt fraction, from the land-treatment area.

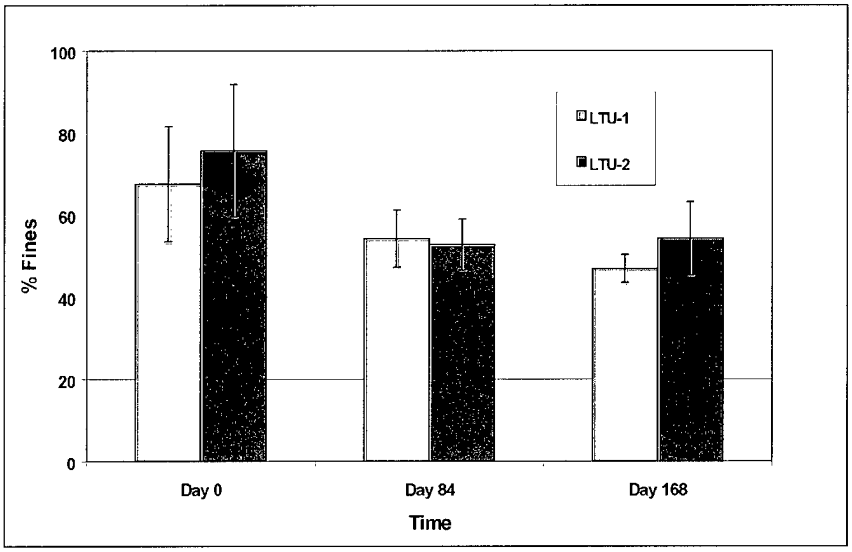

Figure 6. Particle size distribution

Although LTU 1 was cultivated only once (for nutrient homogenization), and LTU 2 was cultivated 17 times throughout the 168-day study, this does not appear to have had a significant impact on the physical structure of the soil.

Soil moisture and field moisture capacity

The field moisture capacity (FMC), as defined by the U.S. Departemnt of Agriculture – Natural Resources Conservation Service, is the moisture content of the soil, expressed as a percentage of the ovendry weight, after the gravitational, or free, water has drained away. More simply, this is the moisture content 2 to 3 days after a soaking rain. It is also known as the normal field capacity, the normal moisture capacity, or the capillary capacity. The Popile soil delivered to the pilot facility had an FMC of 23%. In general, landfarming as bioremediation requires that the moisture content be maintained between 30 and 90% of the FMC to sustain microbial growth. For Popile soil, this correlates to 6.9 to 20.7% moisture. At Day 0, the moisture content was 15 and 14% for LTU 1 and LTU 2, respectively, putting them within the required moisture boundaries. The statement of work (SOW) denoted maintaining the moisture content between 50 and 80% of FMC, translating to a soil moisture content between 11.5% and 18.4% (Figures 7 and 8). The FMC was retested at Day 112 (after a soaking rain). At this time, the LTUs showed an increase in capacity, to 28% for LTU 1 and 30% for LTU 2 (an increase of 21% and 30% for LTU 1 and 2, respectively). Maintaining 50 to 80% FMC, this correlates to a soil moisture content of 14 to 22% for LTU 1 and 15 to 24% for LTU 2. When soil moisture content fell below the 50% FMC minimum, water was added to bring the moisture content up to 80% of the FMC. Maintaining the soil moisture level at over 50% FMC proved problematic. The high concentration of tightly sorbed hydrophobic hydrocarbons repelled moisture (Luthy et al. 1997) in the soil. High temperatures and winds accelerated the evaporative losses.

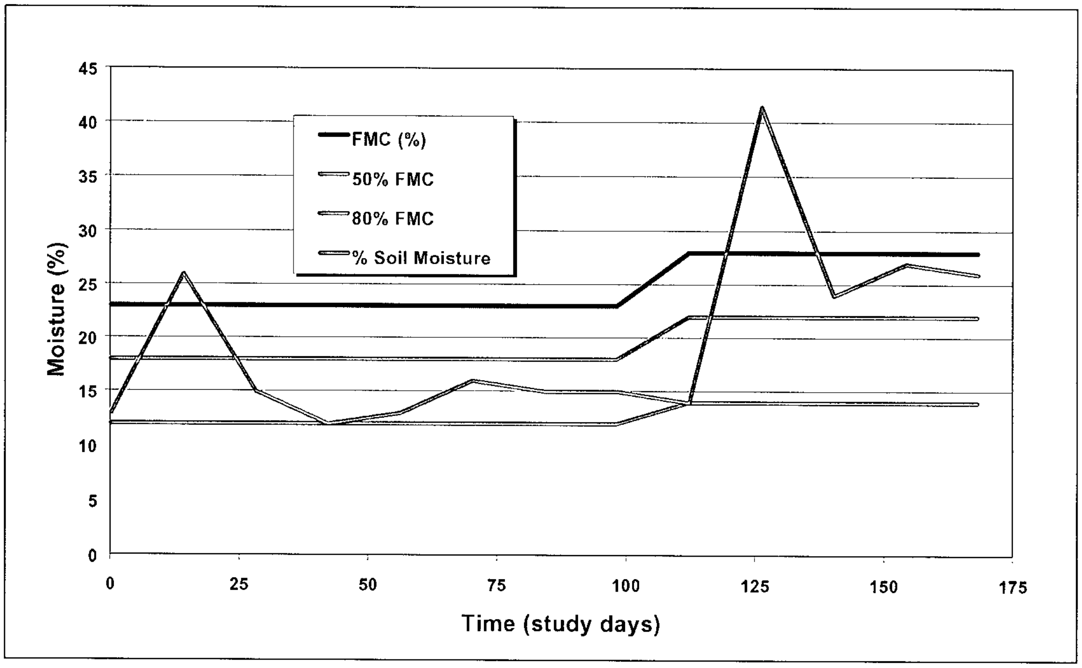

Figure 7. LTU 1. Relationship between soil moisture and field moisture capacity

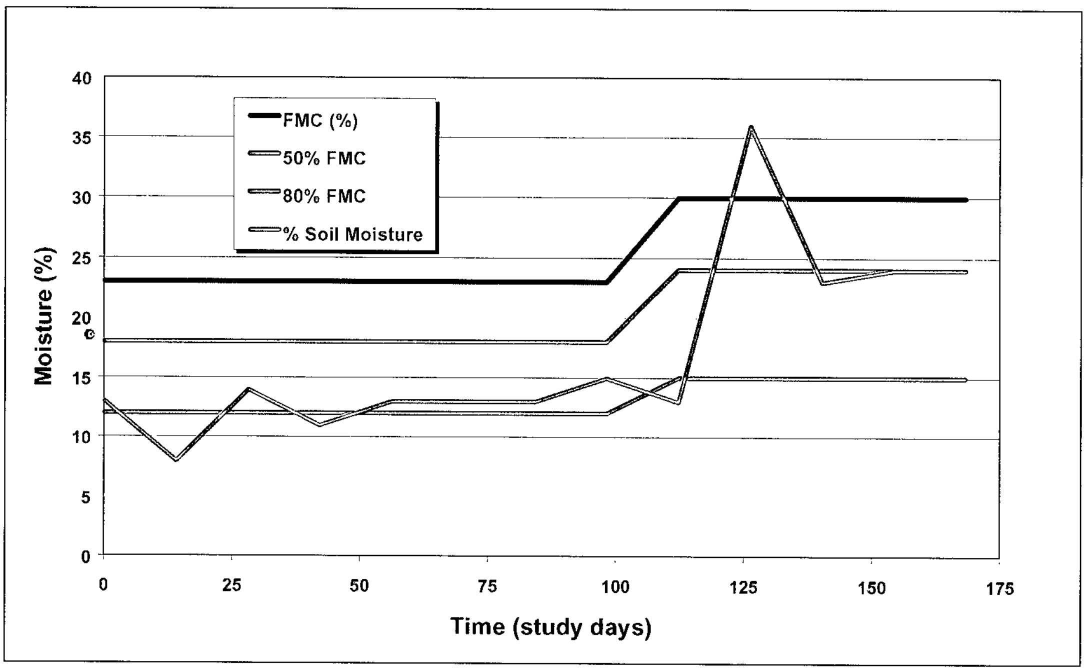

Figure 8. LTU 2. Relationship between soil moisture and field moisture capacity

LTU leaching

Natural rain events and watering to maintain the soil moisture resulted in leachate from the LTUs. Table 4 shows the results of the initial and final leachate analysis. The primary contaminant of the leachate was PCP.

Table 4
Concentrations of Contaminants in LTU Leachate

	Concentration, mg/l	
Contaminant	**Day 14**	**Day 168**
PCP	197.0	
Phenol	3.13	
2-methyl phenol	1.82 (estimated)	
4-methyl phenol	5.3	
Naphthalene	1.0 (estimated)	
Dibenzofuran	1.28 (estimated)	

Note: Blank spaces indicate values below detection limit.

Leachability test

The results of the SBLT leaching test in LTU 1 at Day 14 and Day 168 are shown in Figure 9. The SBLT for LTU 1 on Day 168 showed that only 7.9% of the available PCP was leached from the sample during the test. As time increases, the concentration of PCP decreases. The SBLT indicates that probably less than 10% of the PCP is in a form available for microbial degradation. LTU 2 performed in a similar manner, as shown in Figure 10. In both LTUs, less than 0.5% of the PAHs leached from the samples.

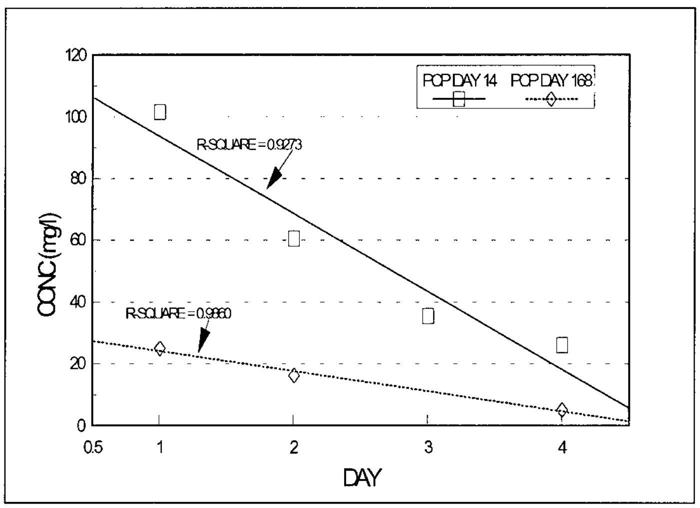

Figure 9. LTU 1. Results of SBLT

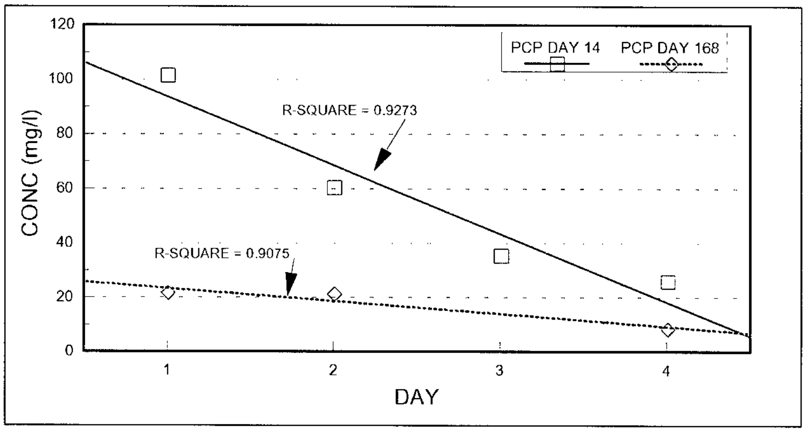

Figure 10. LTU 2. Results of SBLT

The results of the SPLP are shown in Table 5. Both LTU 1 and LTU 2 demonstrated a dramatic decrease in PCP leachability from the beginning to the end of the study. Under these slightly acidic conditions, less than 5% of the PCP was leached from the soil during the SPLP. The PAHs were below detection limits.

Table 5
Synthetic Precipitate Leaching Procedure Test Results

		Day 168	
Compound	**Day 0**	**LTU 1**	**LTU 2**
Pentachlorophenol	34.4±3.0	3.63±0.67	4.71±0.81
Naphthalene	5.8±0.5	0.0	0.0

Chemical Characteristics of the Popile Soil

Nutrients and TOC

A typical soil should have total nitrogen values around 1,500 ppm and total phosphate around 400 ppm (Lyon, Buckman, and Brady 1952). As expected from the landfarming literature (Dibble and Bartha 1979, Golueke and Diaz 1989), the nitrogen in the Popile soil was low (Table 6). The target concentrations for C:N:P of 100:10:1 would correlate to 28,000:2,800:280 in the Popile soil. This initial nitrogen, then, is an order of magnitude lower than our optimal targets. Nitrogen, as NH_4, was added in aqueous form to increase the nitrogen concentration in the system. The aqueous addition was problematic due to the high hydrophobic hydrocarbon concentrations. Solid nitrogen addition was attempted with some success when it coincided with a natural rain event. Phosphate was not limiting in this system. Nitrogen may have been a limiting nutrient. Following nitrogen (fertilizer) addition, there was a burst of microbial growth and CO_2 production.

Table 6 **Initial Nutrient Analysis**	
Nutrient	**Concentration (mg/kg)**
Total Kejldahl Nitrogen (TKN)	158.5±18.13
NO_2-N	1.88 *estimated value
NO_3-N	17±3.5
NH_3-N	4±1.1
Total Phosphate (TP)	456±89
OPO_4	32±10
Total Organic Carbon (TOC)	28,671.5±3,244.5

Metals

Table 7 shows no metals present in the Popile soil at concentrations that would inhibit microbial growth.

Table 7 **Metal Concentrations in Popile Soil**		
	Average Concentration, mg/kg	
Metal	**LTU 1**	**LTU 2**
Lead	12.89	13.03
Nickel	11.14	10.67
Zinc	34.33	34.16
Iron (elemental)	10,457.14	10,371.43
Ferrous iron	22.10	0 (below measurable limits)
Ferric iron	10,420.00	10,371.43
Magnesium	3,768.57	3,687.14
Manganese	45.57	45.04
Arsenic	5.14	4.93
Barium	682.57	673.43
Cadmium	0 (below measurable limits)	0 (below measurable limits)
Chromium	17.64	16.57
Mercury	0.39	0.38
Selenium	0 (below measurable limits)	0 (below measurable limits)

pH

Soil pH affects the contaminant chemistry and interactions with the soil particles. The initial soil pH for both LTUs was 9. This initial pH immediately began decreasing (7.4 at Day 84). However, by Day 168 the pH had returned to 8. Figures 11 and 12 illustrate the interaction between pH and PCP in LTU 1 and 2, respectively. As outlined by Lee et al. (1990), at neutral pH, PCP can be found as both a phenolate anion and in its neutral form. Below pH 7, the neutral species adsorbs to the soil with increasing strength as the pH drops and/or the organic carbon increases. Above pH 7, the ion adsorbs to the soil particles and also can form complexes with soil metals. With Popile soil, we have a situation in which the pH is above 7 at the beginning, the organic carbon content is high (Table 6), and there is a high iron content (Table 7). The PCP possibly was initially complexed to the iron and adsorbed to the organic components of the soil. As the pH decreased, this PCP was released back into the soil, becoming available for degradation and, thus, appearing to increase in concentration.

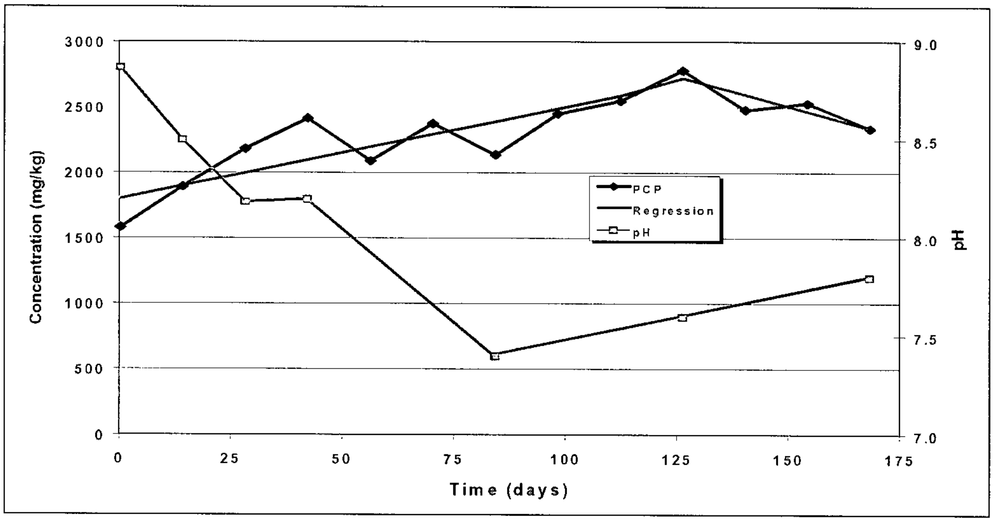

Figure 11. LTU 1. Relationship between soil pH and PCP concentration

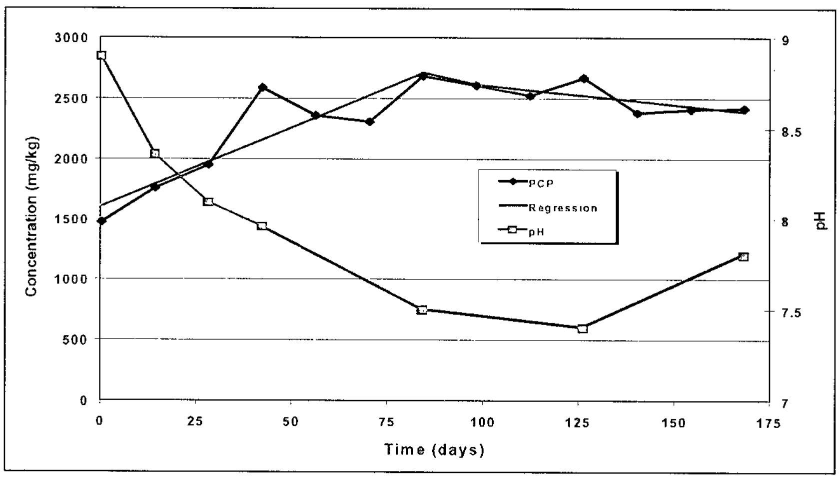

Figure 12. LTU 2. Relationship between soil pH and PCP concentration

Contaminants

Figure 13 illustrates the general decrease in the concentration of PAHs in LTU 1 and 2. LTU 2 showed a greater reduction in the contaminant. No decrease in PCP concentration was seen in either LTU.

When the PAH reduction is examined by individual compound (Figures 14 and 15, and Appendix A), decreases are evident in both LTUs for naphthalene and 2-methylnaphthalene (2-ring compounds). Removal of the 2-ring PAHs generally occurs through a combination of physical (ex. volatilization) and biological processes. LTU 1 also shows a slight decrease in acenaphthalylene, fluoranthene, and phenanthrene (2- and 3-ring compounds). Removal of 3-ring compounds is generally accepted as evidence of biological degradation of PAH due to the low volatility of these compounds.

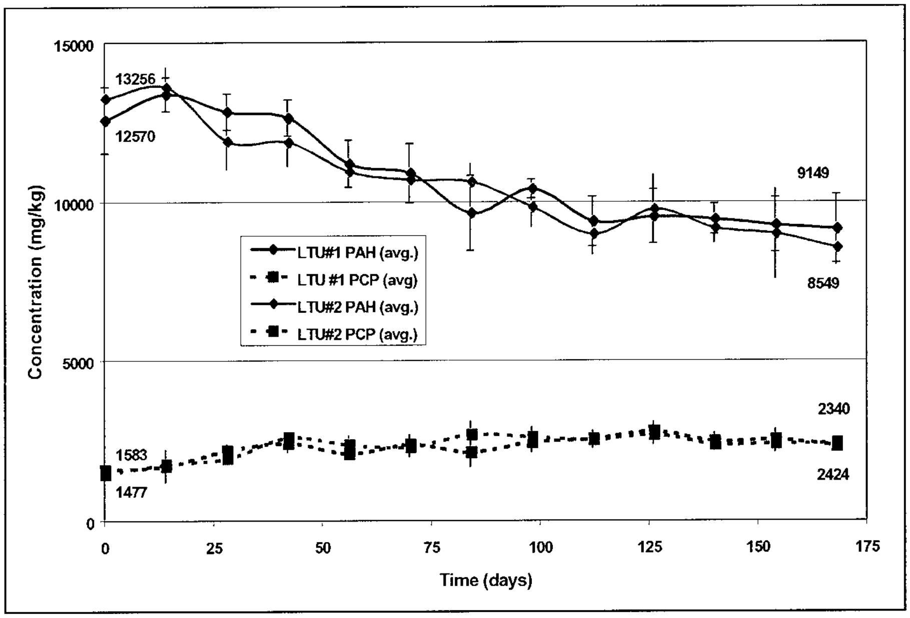

Figure 13. A comparison of PAH and PCP concentrations in LTU 1 and 2

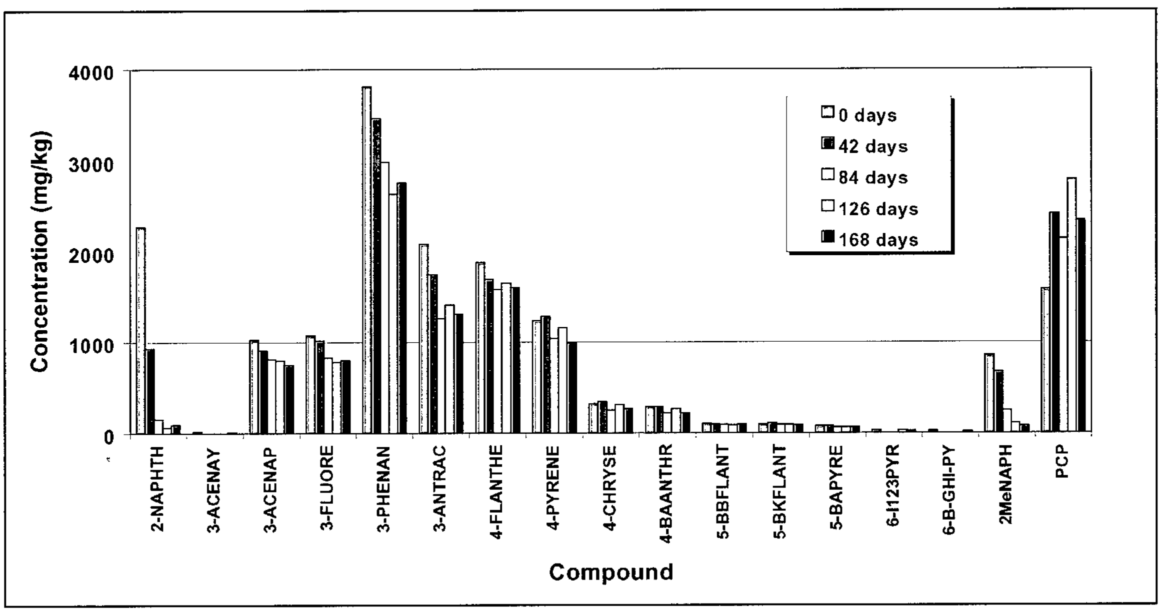

Figure 14. LTU 1. A comparison of PAH and PCP concentrations. The number of rings composing each compound is indicated at beginning of name

In LTU 2, these decreases in concentration of the 2- and 3-ring compounds are greater and include anthracene (3-ring). The increase in PCP concentration is more marked in LTU 2, especially between Day 0 and Day 84, the same period in which the pH was decreasing.

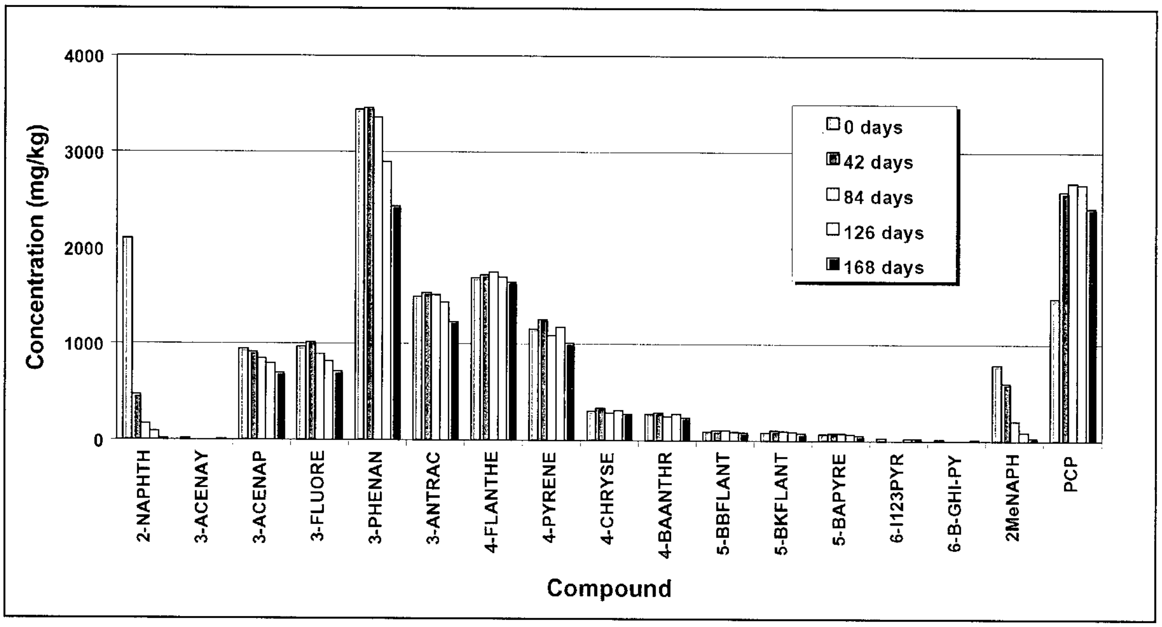

Figure 15. LTU 2. A comparison of PAH and PCP concentrations. The number of rings Composing each compound is indicated at the beginning of each name

BaP equivalents

When the BaP equivalents are calculated (Figure 16), LTU 2 demonstrated a greater overall decrease.

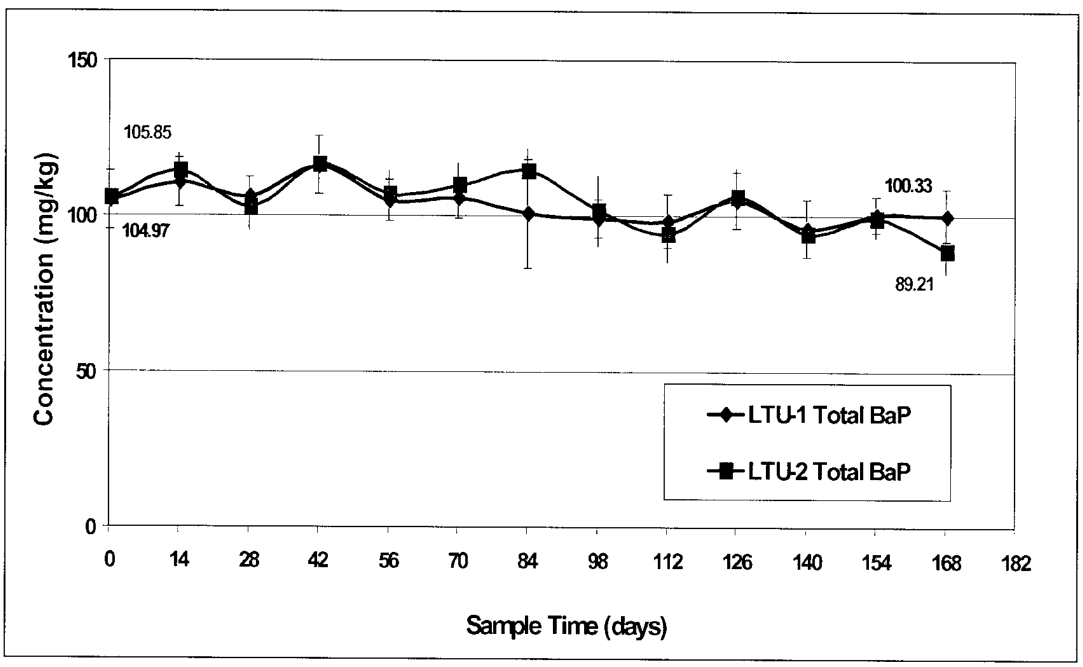

Figure 16. LTU 1 and 2. Comparison of total BaP equivalents

Figures 17 and 18 examine the BaP-equivalent PAH compounds in each LTU. LTU 2 shows a more pronounced decrease in benzo(a)pyrene.

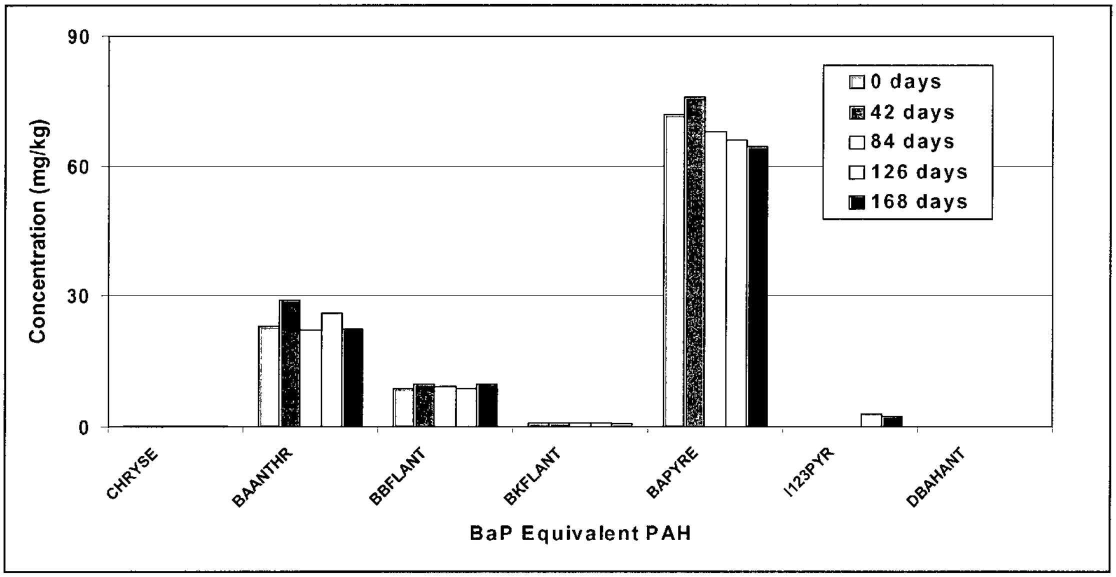

Figure 17. LTU 1. The BaP-equivalent compounds

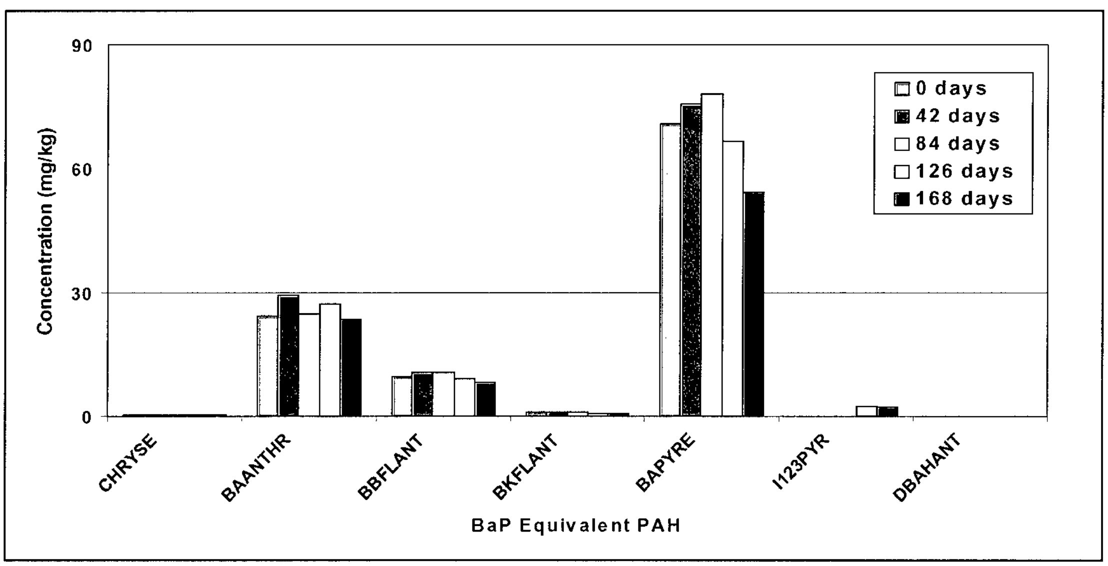

Figure 18. LTU 2. The BaP-equivalent compounds.

Metabolic Characteristics of Popile Soil

Biomass

As shown in Table 8, Figure 19, and Figure 20, viable biomass increased in both LTUs over time. The greatest increase in LTU 1 occurred between Days 42

and 84 . In LTU 2, the greatest increase occurred between Days 84 and 126. Biomass estimates at the endpoint, 168 Days, averaged 4.5×10^8 and 5.5×10^8 cells/g in LTUs 1 and 2, respectively, representing a 2 and 4-fold increase over the Day 0 values (Table 8). However, the 2-fold increase in LTU 1 was insignificant (Tukey HSD, $p<0.05$) whereas the 4-fold increase in LTU 2 was significant (Days 84 through 168 versus Day 0). Biomass differences between LTUs, at common time points, were also insignificant at all time points except Day 126. At this point, the biomass in LTU 2 was significantly greater than that in LTU 1. Viable microbial biomass estimates for the original delivered soil and LTU Day 0 soil were not significantly different.

Table 8
Microbial Biomass and Community Composition

Sample	Viable Biomass Cells/g[1]	Community Composition, mole %			
		Ubiquitous	Gram-positive	Gram-negative	Micro-eukaryote
Dump-1	2.1E+08	85.8	2.5	10.1	1.6
Dump-3	8.4E+07	58.5	4.5	31.1	5.8
Dump-5	1.9E+08	81.8	4.0	12.4	1.7
Dump-7	7.6E+07	47.0	12.1	37.4	3.6
Dump-9	6.5E+07	58.5	4.7	32.2	4.6
Avg., cv[2]	1.3E+08, 56%	66, 25%	6, 67%	25, 51%	3, 53%
T0-L1D	7.0E+08	53.9	5.9	35.2	5.0
T0-L1L	1.0E+08	78.9	2.5	17.6	1.1
T0-L1M	7.3E+07	62.7	3.6	31.4	2.2
T0-L1N	1.9E+08	86.5	1.8	10.5	1.2
T0-L1P	2.4E+08	90.5	1.6	7.2	0.7
T0-L1S	1.8E+08	83.4	2.7	12.8	1.2
Avg., cv	2.5E+08, 93%	76, 19%	3, 53%	19, 61%	2, 84%
T0-L2D	5.5E+07	62.6	5.1	29.8	2.5
T0-L2K	1.6E+08	81.7	3.3	13.7	1.3
T0-L2L	1.7E+08	88.5	1.7	8.9	0.8
T0-L2M	8.1E+07	75.0	23	20.5	2.3
T0-L2N	3.0E+08	91.4	1.3	6.7	0.6
T0-L2P	6.3E+07	53.9	8.4	34.1	3.5
T0-L2S	1.1E+08	54.2	8.3	32.8	4.7
Avg., cv	1.4E+08, 63%	72, 22%	4, 69%	21, 55%	2, 66%

[1] Assuming 1 pmole PLFA is equivalent to 2.5×104 cells.
[2] Coefficient of variation, cv%.

Community composition

No significant differences existed between the major bacterial classifications examined. An important observation was the magnitude of the coefficients of variation (CV) at the beginning of the study and the steady decline in these magnitudes over time (Table 9). This result indicates that, although the contaminant distribution may have been homogeneous at Day 0, microbial community distribution was not. Spatial heterogeneity in microbial biomass and community composition was apparent in the original delivered soil and in both LTUs. The values shown represent the average of all replicate sample (n = 7) per time point per LTU.

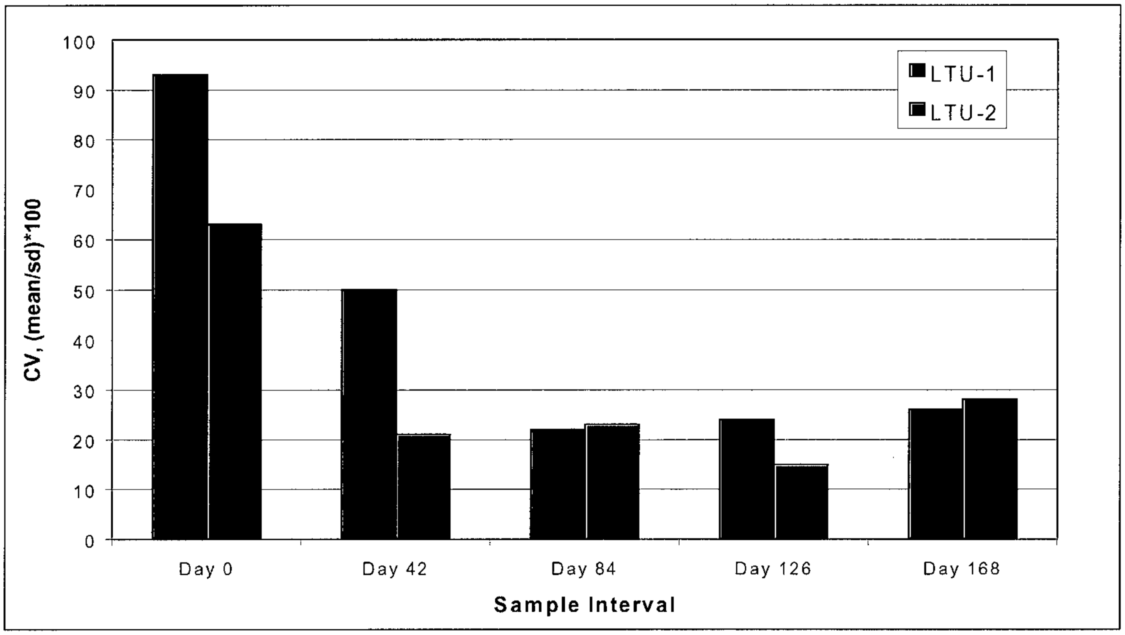

Figure 19. Coefficients of variation for LTU viable microbial biomass

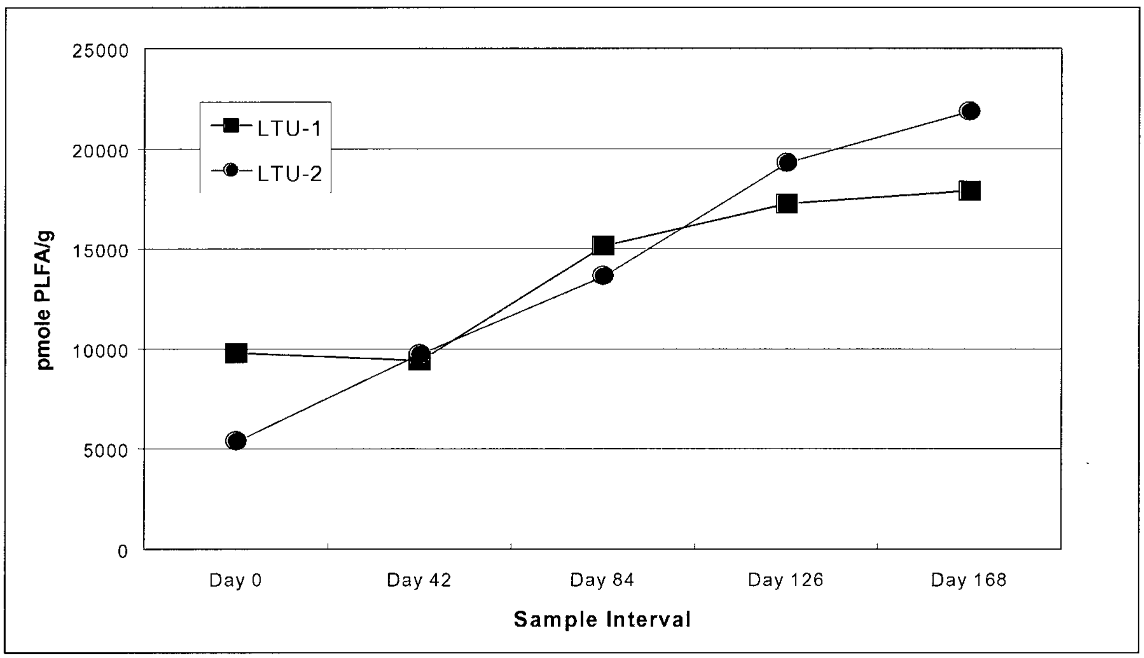

Figure 20. Microbial biomass in LTU 1 and LTU 2

Over the time of the study, both LTUs showed significant increase in the percentages of PLFA that are indicative of Gram-negative bacteria (Figure 21). In contrast, PLFA descriptive of Gram-positive bacteria remained at the Day 0 levels or declined slightly (Figure 22). The Gram-negative increase correlated with the biomass increase in both LTUs ($r = 0.777$ for LTU 1 and 0.895 for LTU 2). Significant differences between Day 0 and all subsequent time points were measured.

Table 9 **Microbial Biomass and Community Composition in LTU 1 and 2**					
	Viable Biomass		**Community Composition, mole %**		
Sample	**pmol PLFA/g**	**cells/g**[1]	**Ubiquitous**	**Gram-positive**	**Gram-negative**
Day 0-L1	9805	2.5E+08 (93%)[2]	76 (19%)	3 (53%)	19 (61%)
Day 0-L2	5401	1.4E+08 (63%)	72 (22%)	4 (69%)	21 (55%)
Day 42-L1	9416	2.4E+08 (50%)	57 (6%)	3 (27%)	39 (8%)
Day 42-L2	9746	2.4E+08 (21%)	55 (4%)	3 (29%)	41 (5%)
Day 84-L1	15189	3.8E+08 (22%)	47 (5%)	3 (42%)	50 (6%)
Day 84-L2	13665	3.4E+08 (23%)	50 (6%)	4 (51%)	46 (7%)
Day 126-L1	17275	4.3E+08 (24%)	50 (4%)	4 (48%)	45 (3%)
Day 126-L2	19326	4.8E+08 (15%)	51 (9%)	3 (40%)	45 (9%)
Day 168-L1	17925	4.5E+08 (26%)	45 (7%)	4 (25%)	51 (6%)
Day 168-L2	21889	5.5E+08 (28%)	41 (5%)	3 (24%)	55 (4%)

[1] Assuming 1 pmole, PLFA is equivalent to 2.5 × 104 cells.
[2] Coefficient of variation, cv%.

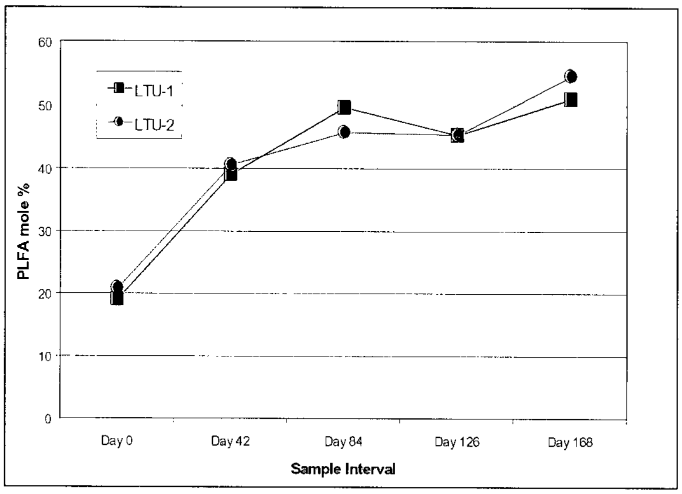

Figure 21. Relative abundance of Gram-negative bacteria

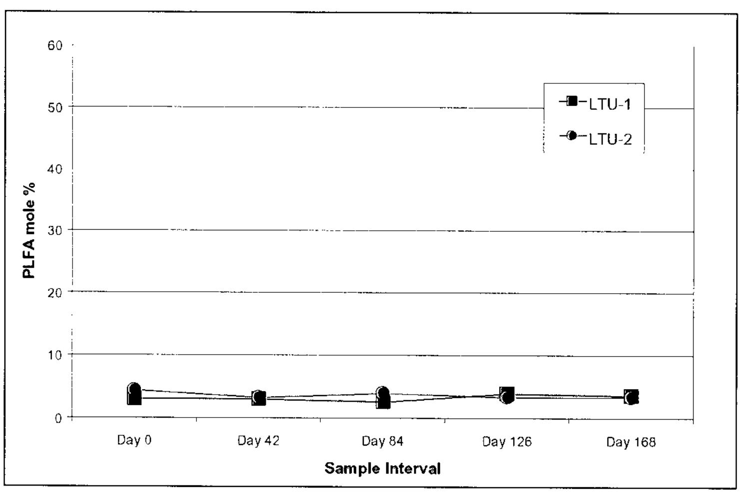

Figure 22. Relative abundance of Gram-positive bacteria

The community composition showed signs of divergence from Day 84 onward. The divergence was first identified by hierarchial cluster analysis. Using the results of this analysis, five of the seven replicate subsamples from each LTU were identified which showed a definable similarity (i.e., all were linked at a euclidean distance of 2.0 or less). PLFA profiles of the five replicate samples are presented in Figure 23 which shows only the Day 168 endpoint analysis, since the community differences identified at Day 84 were also identified at Day 168 with only the magnitude of the divergence changing (i.e., increasing). Six PLFA differed significantly between the two LTUs. Within the ubiquitous PLFA classification, normal saturated 14:0 or myristic acid and 18:0 or stearic acid were identified. Within the Gram-negative classification, two cyclopropyl PLFA (cy17:0 and cy19:0) and two *trans* monounsaturated PLFA (16:1w7t and 18:1w7t) were identified. Since none of the PLFA within the Gram-positive classification differed significantly between LTUs, it can be assumed that the input of these organisms (Gram-positive) to the overall functioning of the LTUs is negligible. The Gram-negative input was, however, highly significant.

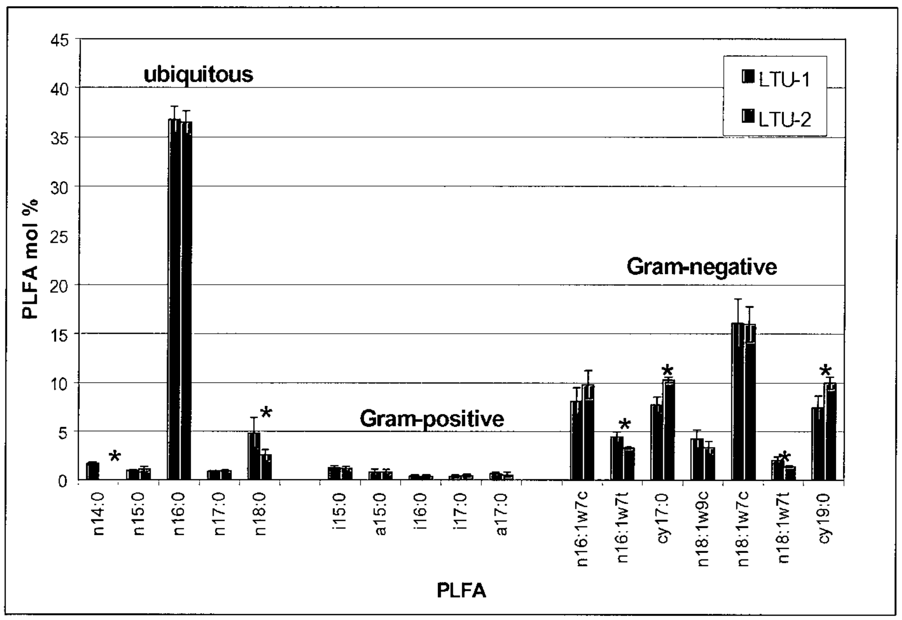

Figure 23. Microbial community composition in both LTUs at Day 168

Increased percentages of myristic and *trans* PLFA in LTU 1 are conducive to the presence of the *Pseudomonas* sp. of bacteria. *Pseudomonas* sp. are consistently isolated from PAH contaminated sites, and a number of species have been demonstrated to have the capacity to mineralize some of these compounds. The increased percentages of cyclopropyl PLFA in LTU 2 is also conducive to the presence of *Pseudomonas* species but reflects a physiological response to changing environmental conditions. In fact, both *trans* and cyclopropyl PLFA are synthesized by Gram-negative bacteria in response to changing environmental conditions, and the divergence seen with the analyses described above likely incorporates this phenomenon as well as any taxonomic differences.

Trans acids have increased in prevalence inside the bacterial membrane in response to toxic exposures. Cyclopropyl PLFA have occurred at different concentrations throughout the bacterial growth phase. Typically, high cyclopropyl PLFA concentrations are taken as a sign of an old and tired Gram-negative bacterial community. To measure the impact of the environment on the formation of these two PLFA classes (*trans* and cyclopropyl), the respective concentrations must be normalized to a related factor such as the parent compound.

The ratio of 16:1w7(*trans*) to 16:1w7(*cis*), product-to-parent compound, suggests an increasing bacterial response by the indigenous bacteria to the presence of the xenobiotics in the soil. The increased response was significant in both LTUs at all time points, compared to the Day 0 values. Only Day 168 (final) values showed a significant difference between LTUs. These results are consistent with bioslurry microcosm studies where PAH concentrations often exceed initial values by 20 to 30% after a relatively short period of incubation. An increase in the bioavailability of the toxicant would induce an increase in the *trans/cis* ratio.

Cy17:0 is also derived from the parent monounsaturate 16:1w7c, and statisticaly significant increases in this ratio were also observed at all time points (with respect to the Day 0 values). There was, however, no significant difference between the two LTUs at any of the time points. This is interesting, since the total cyclopropyl abundance was greater in LTU 2. This suggests that differences in taxonomy are also a contributing factor to the divergence between LTUs. Nevertheless, the increasing prevalence of cyclopropyl PLFA likely indicates the occurrence of "old age" in at least a portion of the Gram-negative bacterial population. If the microorganisms in the LTUs become stimulated (for example, due to tilling), then nutrient pools (if not supplemented) will become limiting and cell growth will be slowed. Once in the stationary phase of the growth cycle, bacteria, in particular Gram-negative bacteria, will synthesize cyclopropyl PLFA.

Respiration gas analysis

Figures 24 and 26 depict the concentrations of oxygen and carbon dioxide in the soil of LTU 1 and 2, respectively. In both LTUs, the peaks of CO_2 production correspond to O_2 depletion. Especially evident in LTU 2, the trend during the final 2 months of sampling was toward an increase in CO_2 production and a decrease in the soil O_2 concentration. The effects of water, the addition of nitrogen, and the effects of tilling on respiration in LTU 1 and LTU 2 are depicted in Figures 25 and 27, respectively. Cultivation and nitrogen addition both appear to have a positive effect on the production of carbon dioxide.

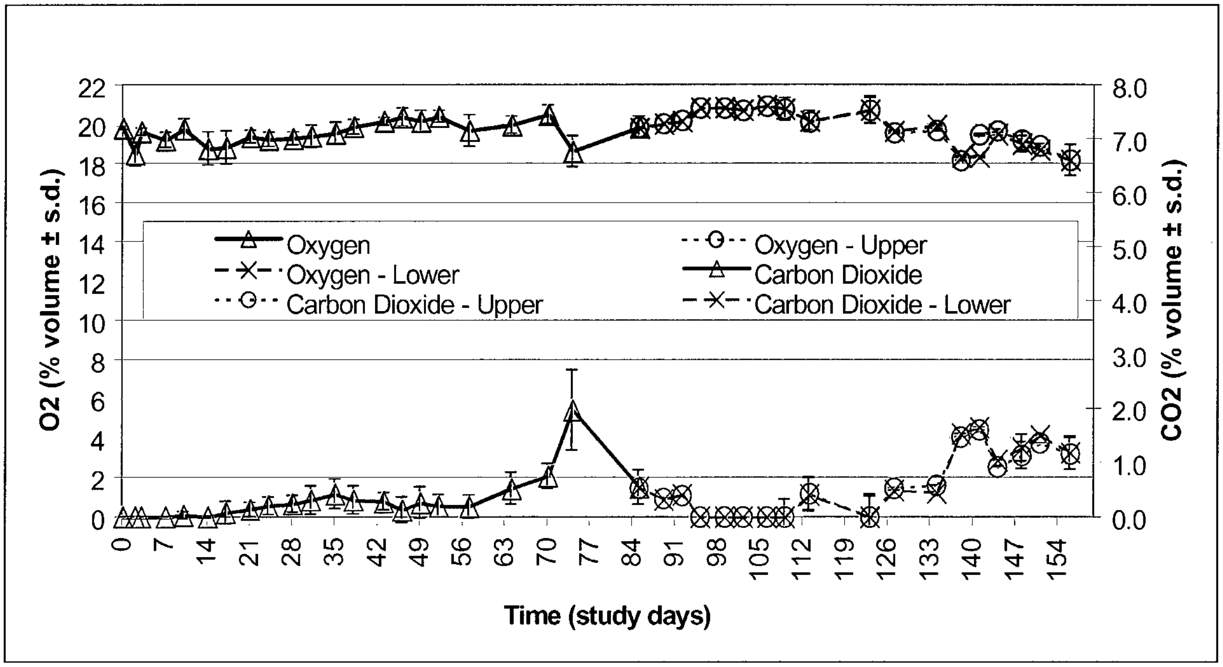

Figure 24. LTU 1. Respiration

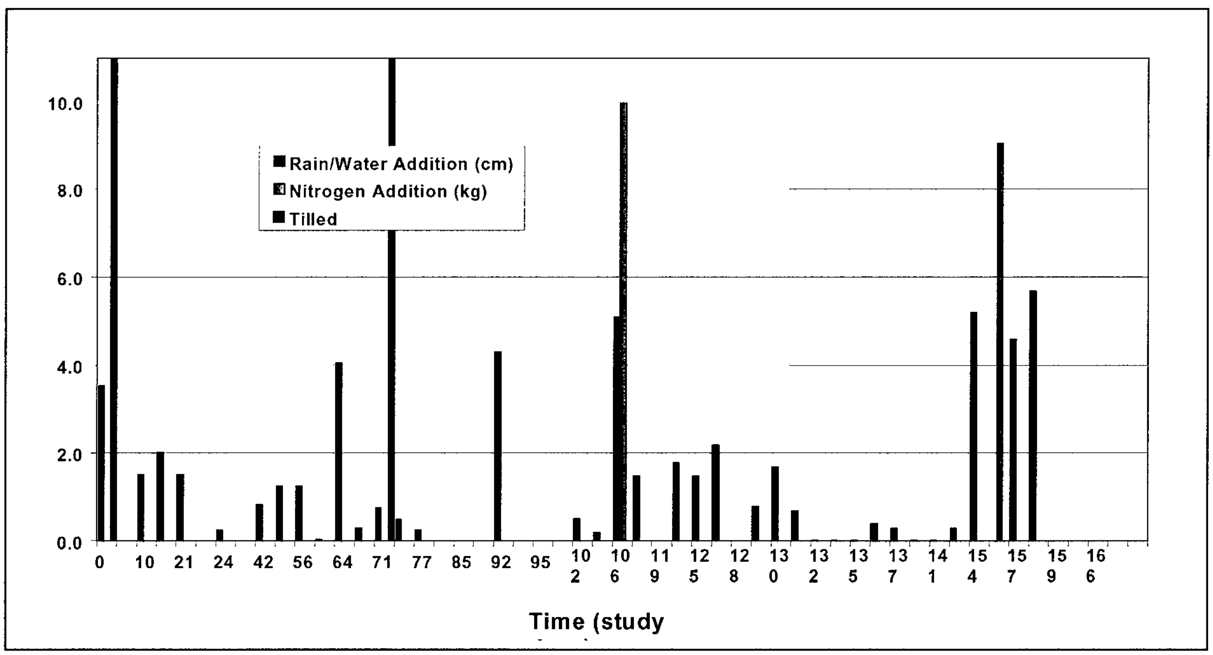

Figure 25. LTU 1. Water and nutrient addition, and tilling

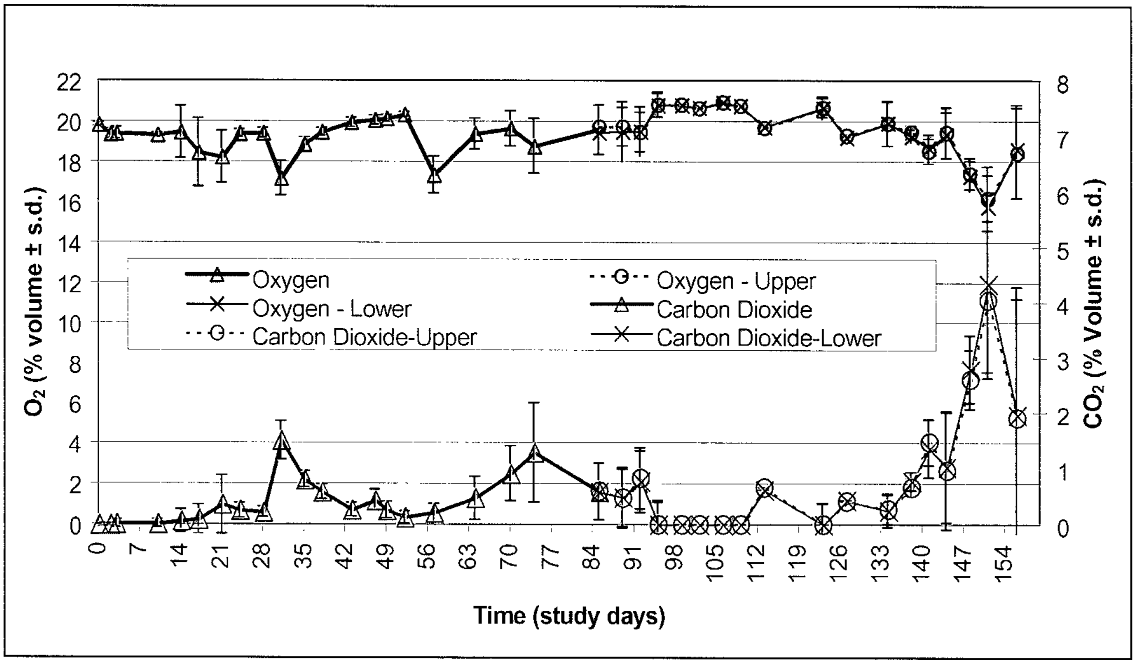

Figure 26. LTU 2. Respiration

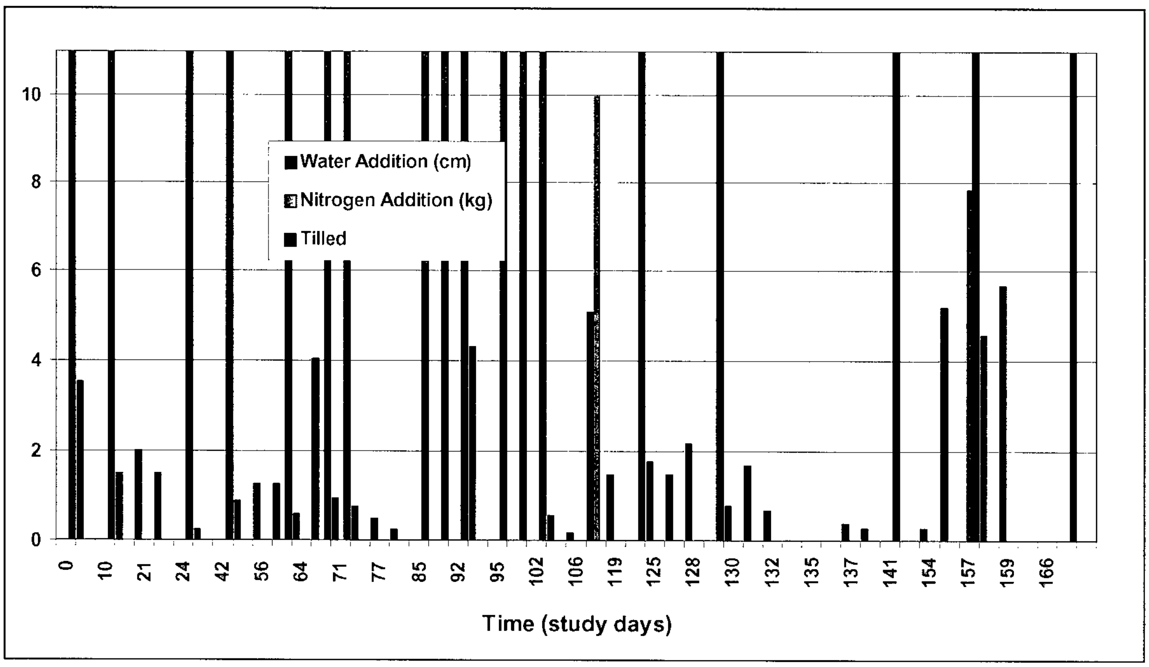

Figure 27. LTU 2. Water and nutrient additions, and tilling

Data Analysis

Contaminant reduction

When the percent reduction from the initial concentration is calculated, they indicate an 8% greater reduction in overall PAH in LTU 2 than LTU 1 (Table 10). This difference is even more apparent when the BaP equivalents are calculated. Then it becomes an 11.3% difference in reduction.

Table 10
Reduction (%) from Initial Concentrations of PAHs and BaP Equivalents

	% Reduction	
Contaminant	**LTU 1**	**LTU 2**
PAH (overall, avg)	27.21	35.5
Naphthalene (2-ring)	95.95	99.17
Anthracene (3-ring)	37.12	17.26
Phenanthracene (3-ring)	27.66	29.10
Pyrene (4-ring)	19.89	12.37
Benzo-(g,h,i)-pyrene (6-ring)	16.32	17.79
BaP Equivalents (overall avg)	4.45	15.76
Chrysene (4-ring)	19.40	8.31
Benzo(a)anthracene (4-ring)	22.63	13.76
Benzo(a)pyrene (5-ring)	10.88	17.85
Indeno-(1,2,3)-pyrene (6-ring)	17.30	18.86

Degradation kinetics

The degradation kinetics (Tables 11 and 12) show that, based on zero-order degradation, at the present rate of decrease, it will take 1.69 years to reduce the overall PAH burden of the Popile soil to 5 ppm without treatment (LTU 1). To reach the goal of 5 ppm BaP equivalents, however, will take 9.86 years. For LTU 2, the average PAH reduction will require 1.3 years. The BaP goal, however, will only take 2.79 years.

Degradation of PCP mentioned earlier, discusses the relationship between soil pH and PCP concentration. The PCP concentration in LTU-1 reached a peak after 126 days and then declined throughout the duration of the study (Day 168). In LTU 2, the peak of PCP concentration was attained earlier in the study (at 42 days) and maintained until Day 126, when it began a slow decline. The apparent rise and fall in PCP concentration in the LTUs appears to be an artifact of soil pH changes. The time elapsed between the respective PCP peak concentrations and Day 168 was insufficient to separate artifact from true degradation and attain reliable kinetic data.

Table 11
Degradation Kinetics of PAHs in LTU 1 and 2

	Degradation Kinetics			
	LTU 1		LTU 2	
Contaminant	**K, ppm/day**	**Time, yr**	**K, ppm/day**	**Time, yr**
PAH (avg)	20.36	1.69	28.02	1.3
Naphthalene (2-ring)	12.98	0.48	12.42	0.46
Phenanthrene (3-ring)	6.28	1.66	5.95	1.58
Anthracene (3-ring)	4.60	1.24	1.53	2.66
Pyrene (4-ring)	1.46	2.31	0.85	3.70
Indeno-(1,2,3)-pyrene (6-ring)	0.03	2.20	0.03	1.98

Table 12
Degradation Kinetics of BaP-Equivalent Compounds in LTU 1 and 2

	Degradation Kinetics			
	LTU 1		LTU 2	
Contaminant	**K, ppm/day**	**Time, yr**	**K, ppm/day**	**Time, yr**
BaP Equivalents	0.028	9.86	0.099	2.79
	0.37	2.36	0.15	5.36
Benzo(a)anthacene (4-ring)	0.39	2.01	0.22	3.33
Benzo(a)pyrene (5-ring)	0.05	3.70	0.07	2.39
Benzo-(g,h,i)-pyrene (6-ring)	0.02	2.42	0.02	2.01

6 Summary and Conclusions

Based on the objectives of treatment goals, kinetics, and leaching potential, this study suggests:

a. ROD treatment goals will not be met using a 6-month lift design in a landfarming system.

b. ROD treatment goals for BaP may be met by extending the duration of each lift treatment. The duration of the study was too short to demonstrate conclusive biodegradation of PCP.

c. Cultivation associated with landfarming did not increase the leachability of contaminants in the Popile soil. The leach data supports the groundwater model showing that the contaminant is not moving from the site under these test conditions. However, in time some change could occur that would render the contaminant mobile and it could migrate to the groundwater.

Beyond meeting the stated objectives of the study, the following pertinent observations were made. The high concentration of hydrophobic contaminants inhibited aqueous phase nutrient additions. Slow-release nutrients applied in a solid form should be a more effective method of maintaining appropriate C:N:R: ratios. The increase in microbial biomass and the change in community makeup in LTU 2 by the end of the study suggest biodegradation of the more recalcitrant PAHs, since LTU 2 saw a greater reduction in benzo(a)pyrene and other 4- and 5-ring PAHs. Cultivation had a positive impact on the degradation kinetics shown by the greater overall decrease in contaminant in LTU 2 over LTU 1.

7 Recommendations

The U.S. Engineer Research and Development Center (ERDC) recommends that the U.S. Army Engineer District, New Orleans (USAEDNO), consider continued leveraged funding of Popile, Phase III, pilot-scale activities. The ERDC is the center of the Federal Integrated Biotreatment Research Consortium (FIBRC), a research and development project of the Strategic Environmental Research and Development Project (SERDP). Remediation of PAH-contaminated material is a thrust of FIBRC. Dr. Hap Pritchard, Naval Research Laboratory (NRL), is the Thrust Area Leader. Dr. Pritchard has observed the development of pilot-scale landfarming expertise between ERDC and the USAEDNO. This has resulted in a request for a collaborative continuation between ERDC, FIBRC, and USAEDNO of the Popile study.

The FIBRC plan is to innoculate the treated Popile soil with known PAH-degrading bacteria from NRL. These microorganisms have been isolated and cultured as part of the SERDP-FIBRC effort. The FIBRC will contribute to the cost of this effort.

The benefit to USAEDNO, EPA, and the State of Arkansas, Department of Environmental Quality, is a potential treatment protocol that will meet the ROD goals and further develop an emerging technology consistent with the objectives of the USACE Innovative Technology Advocate Initiative.

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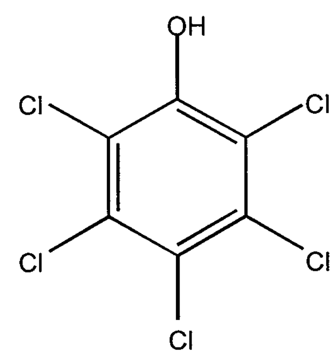
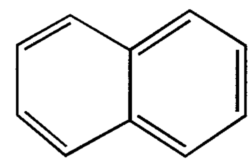
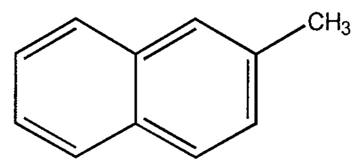
Appendix A
Contaminant Structures

Pentachlorophenol

Name	Abbreviation	Structure
pentachlorophenol	PCP	

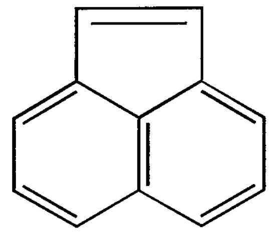
Polycyclic Aromatic Hydrocarbons

2-Ring Compounds

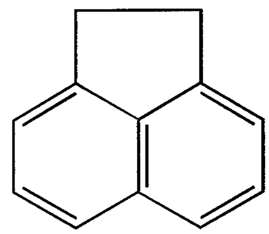
Name	Abbreviation	Structure
Napthalene	NAPHTH	
2-methylnaphthalene	2-MeNAPH	

3-Ring Compounds

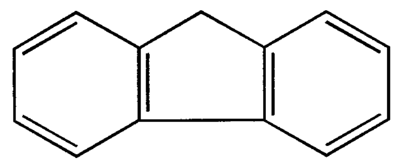
Acenaphthylene ACENAY



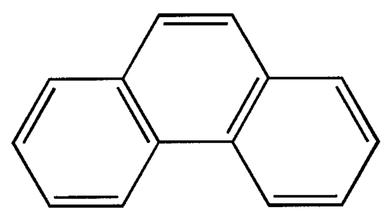
Acenaphthene ACENAP



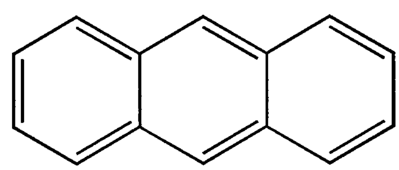
Fluorene FLUORE



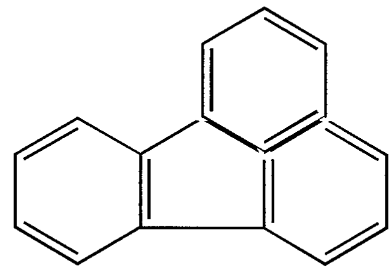
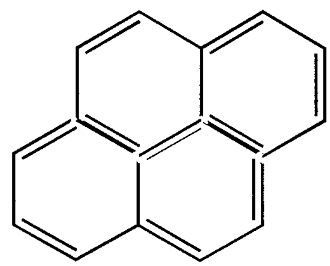
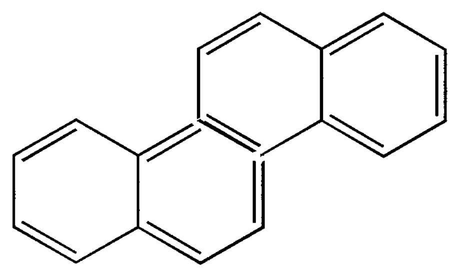
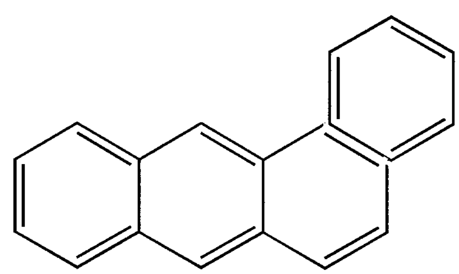
Phenanthrene PHENAN



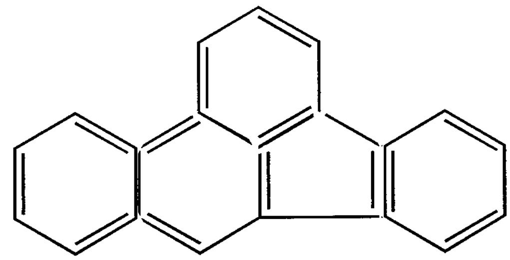
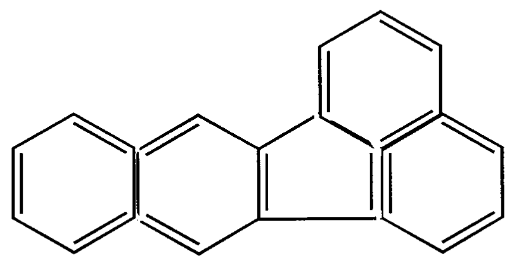
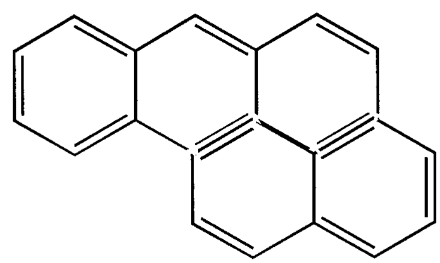
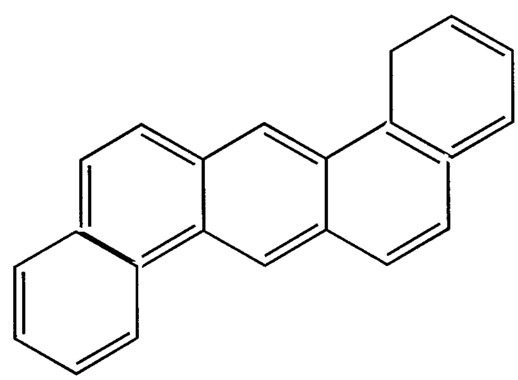
Anthracene ANTRAC



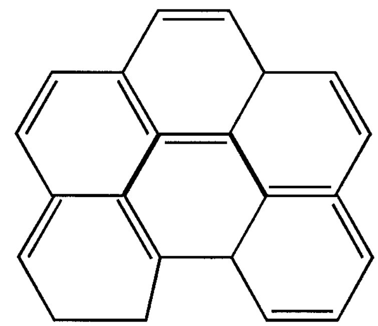
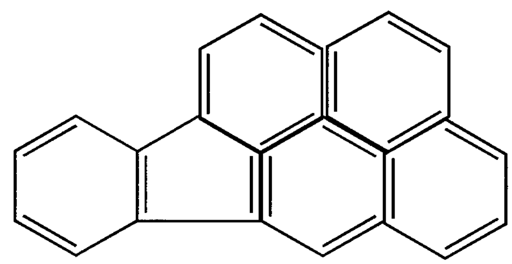
4-Ring Compounds

Name	Abbreviation	Structure
Fluoranthene	FLANTHE	
Pyrene	PYRENE	
Chrysene	CHRYSE	
Benzo(a)anthracene	BAANTHR	

5-Ring Compounds

Name	Abbreviation	Structure
Benzo(b)fluoranthene	BBFLANT	
Benzo(k)fluoranthene	BKFLANT	
Benzo(a)pyrene	BAP	
Dibenzo(a,h,)anthracene	DBAHANT	

6-Ring Compounds

Name	Abbreviation	Structure
Benzo(g,h,i)perylene	B-GHI-PY	
Indeno(1,2,3-c,d)pyrene	I123PYR	

Appendix B
LTU Data

	Initial Characterization of Popile Soil											
Replicate	1	2	3	4	5	6	7	8	9	10	avg	stdev
PARTICLE SIZE DISTRIBUTION												
%GRAVEL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.00	
% SAND	43.4%	32.5	22.06	33.35	52.31	41.07	30.19	39.63	41.18	22.01	31.47	14.28
% FINES (silt, clay)	56.6	67.5	77.94	66.65	47.69	58.93	69.81	60.37	58.82	77.99	64.23	9.60
NUTRIENT ANALYSIS, mg/kg												
TKN	171	150	168	173	187	167	140	132	157	140	158.5	18.13
TP	439	371	391	432	465	691	423	475	459	413	455.9	88.77
OPO4	33	59.8	29.3	25.4	26.1	26.1	35.3	27.8	28.4	26.3	31.75	10.37
NO2-N	1.88	<1.42	<1.39	<1.28	<1.32	<1.37	<1.36	<1.36	<1.23	<1.35	1.88	
NO3-N	16.7	16.1	19.8	19.2	18.9	22	12.9	18.1	16.2	10.1	17	3.47
NH3-N	3.1	4.12	5.43	5.78	2.72	2.59	4.11	3.4	3.95	4.76	4.00	1.09
pH	8.7	9.3	8.8	8.8	8.9	8.6	8.9	8.9	9.0	8.9	8.9	0.18
TVS (% by wgt)	6.47%		7.50%		5.37%						6.45%	0.01
MOISTURE %	13.4		12.5		13.2						13%	0.47

Initial Characterization of the Popile Soil. The PAH and PCP Contaminant Concentrations, mg/kg

Replicate	1	2	3	4	5	6	7	8	9	10	avg	stdev	BaP CF	BaP Equiv.
PCP	774	1110	867	637	631	618	629	820	699	960	774.50	166.15		
NAPHTH	2,130	1,943	1,880	1,810	2,090	1,800	1,750	1,650	1,760	2,010	1882.30	157.38		
ACENAY	25	22	22	21	24	22	21	19	20	24	22.00	1.89		
ACENAP	976	882	841	814	960	864	815	787	800	942	868.10	69.49		
FLUORE	1160	974	919	943	1060	987	923	878	885	1080	980.90	92.28		
PHENAN	3480	3110	2970	2980	3340	3040	2840	2790	2900	3360	3081.00	236.81		
ANTRAC	2150	1310	1180	1460	1530	1410	1290	1250	1230	1650	1446.00	287.60		
FLANTHE	1720	1570	1490	1470	1700	1540	1460	1450	1490	1670	1556.00	104.16		
PYRENE	1060	966	902	892	999	946	899	851	890	1030	943.50	68.65		
CHRYSE	294	251	243	251	284	264	239	233	238	285	258.20	22.23	0.001	0.26
BAANTHR	261	230	214	216	245	225	213	208	210	251	227.30	18.87	0.100	22.73
BBFLANT	98	97	89	83	100	85	79	92	95	110	92.80	9.19	0.1	9.28
BKFLANT	99	98	90	75	95	100	80	83	74	98	89.20	10.32	0.01	0.89
BAPYRE	76	72	67	68	77	69	65	67	67	72	70.00	4.08	1	70.00
I123PYR	31	25	21	26	31	29	22	25	26	29	26.50	3.47	0.1	2.65
DBAHANT	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	0.00	0.00	1	0.00
DBENZOFU	773	677	667	662	758	703	644	609	636	739	686.80	54.83		
2MeNAPH	813	697	675	661	776	685	671	622	650	763	701.30	61.74		
Total PAHs	15146	12924	12270	12432	14069	12769	12011	11614	11971	14113	12931.9	1145.67		
Total BaP														105.81

SAMPLE DAY 0	6-Jul-98											
LTU 1	Contaminant Concentration, mg/kg											
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Eqiv	BaP Stdev
LTU 1												
PAH - single extraction												
NAPHTH	2210	2060	1950	2430	1980	2070	2010	2101.43	167.57			
ACENAY	<290	<290	<290	<290	<290	<290	<290					
ACENAP	899	878	826	998	825	855	866	878.14	59.20			
FLUORE	1030	959	892	1130	906	987	957	980.14	80.87			
PHENAN	3270	3120	2940	3590	2960	3210	3090	3168.57	221.32			
ANTRAC	1930	1230	1180	1790	1200	1610	1230	1452.86	317.21			
FLANTHE	1590	1380	1390	1520	1470	1460	1410	1460	75.72			
PYRENE	1000	1130	942	1260	914	963	999	1029.71	122.78			
CHRYSE	**255**	**265**	**257**	304	**245**	**258**	**255**	262.71	19.14	0.001	0.26	0.02
BAANTHR	**240**	**231**	**219**	**254**	**223**	**218**	**220**	229.29	13.46	0.1	22.93	1.35
BBFLANT	**104**	**92.7**	**76.2**	**94.7**	**88.8**	**89.8**	**78.5**	89.24	9.54	0.1	8.92	0.95
BKFLANT	**104**	**93.2**	**76.7**	**95.3**	**89.3**	90.5	**86.1**	90.73	8.40	0.01	0.91	0.08
BAPYRE	**77.3**	**74.7**	**66.3**	**83.9**	**65.9**	**65.5**	**70**	71.94	6.99	1	71.94	6.99
I123PYR	<290	<290	<290	<290	<290	<290	<290			0.1		0.00
DBAHANT	<290	<290	<290	<290	<290	<290	<290			1		0.00
B-GHI-PY	<290	<290	<290	<290	<290	<290	<290					
2MeNAPH	772	780	695	857	714	742	725	755	54.26			
PCP	2050	1660	1600	1420	1500	1390	1460	1582.86	227.36			
TOTAL PAHs	13481.3	12293.6	11510.2	14406.9	11681	12618.8	11996.6	12569.77	1042.89			
TOTAL BaP											104.97	

SAMPLE DAY 0	6-Jul-98											
LTU 2	**Contaminant Concentration, mg/kg**											
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH - single extraction												
NAPHTH	2260	2270	2110	2090	2170	2260	2140	2185.71	76.78			
ACENAY	<290	<290	<290	<290	<290	<300	<300					
ACENAP	969	969	930	910	941	942	922	940.43	22.40			
FLUORE	1050	1020	1010	986	1040	1030	1020	1022.29	20.89			
PHENAN	3480	3450	3280	3270	3360	3400	3280	3360	86.60			
ANTRAC	1510	1420	1470	1640	1460	1680	1460	1520	99.83			
FLANTHE	1600	1650	1610	1530	1600	1640	1520	1592.86	50.24			
PYRENE	1100	1090	1120	988	1060	1040	1050	1064	44.11			
CHRYSE	**280**	**285**	**259**	**264**	**281**	**283**	**266**	274	10.61	0.001	0.274	0.01
BAANTHR	**242**	**254**	**236**	**234**	**241**	**240**	**233**	240	7.09	0.1	24.2	0.71
BBFLANT	**104**	**113**	**98.2**	**96.6**	**100**	**96.7**	**86.5**	99.29	8.06	0.1	9.56	0.81
BKFLANT	**101**	**93.5**	**98.1**	**92.1**	**87.7**	**95.1**	**99.5**	95.29	4.64	0.01	0.945	0.05
BAPYRE	**71**	**72**	**70.2**	**67.1**	**75.7**	**77.9**	**63.5**	71.06	4.88	1	70.88	4.88
I123PYR	<290	<290	<290	<290	<290	<300	<300			0.1	0	0.00
DBAHANT	<290	<290	<290	<290	<290	<300	<300			1	0	0.00
B-GHI-PY	<290	<290	<290	<290	<290	<300	<300					
2MeNAPH	810	815	780	770	790	804	754	789	22.40			
PCP	1960	1620	1560	1300	1340	1310	1250	1477.14	255.00			
TOTAL PAHs	13577	13501.5	13071.5	12938	13206	13589	12894.5	13253.91	300.67			
TOTAL BaP											105.86	

SAMPLE DAY 0	6-Jul-98							
LTU 1	Contaminant Concentration, mg/kg							
Replicate	1	2	3	avg	stdev	BaP CF	BaP Eqiv	BaP Stdev
PAH-double extraction								
NAPHTH	2350.00	2230.00	2240.00	2273.33	66.58			
ACENAY	**17.00**	**17.00**	**23.00**	19.00	3.46			
ACENAP	1030.00	1010.00	1030.00	1023.33	11.55			
FLUORE	1080.00	1100.00	1040.00	1073.33	30.55			
PHENAN	3850.00	3800.00	3780.00	3810.00	36.06			
ANTRAC	1830.00	2760.00	1650.00	2080.00	595.73			
FLANTHE	1920.00	1820.00	1900.00	1880.00	52.92			
PYRENE	1230.00	1230.00	1250.00	1236.67	11.55			
CHRYSE	329.00	319.00	324.00	324.00	5.00	0.00	0.32	0.01
BAANTHR	298.00	286.00	289.00	291.00	6.24	0.10	29.10	0.62
BBFLANT	94.60	110.00	98.80	101.13	7.96	0.10	10.11	0.80
BKFLANT	99.70	87.60	102.00	96.43	7.74	0.01	0.96	0.08
BAPYRE	71.30	72.40	73.90	72.53	1.31	1.00	72.53	1.31
I123PYR	**27.00**	30.10	30.10	29.07	1.79	0.10	2.91	0.18
DBAHANT	<30	<30	<30	0.00	0.00	1.00	0.00	0.00
B-GHI-PY	**22.00**	**23.00**	**23.00**	22.67	0.58			
2MeNAPH	869.00	842.00	850.00	853.67	13.87			
PCP	2460.00	2050.00	2410.00	2306.67	223.68			
Total PAH	15117.60	15737.10	14703.80	15186.17	520.05			
Total BaP							115.94	

SAMPLE DAY 0	6-Jul-98							
LTU 2	Contaminant Concentration, mg/kg							
Replicate	1	2	3	avg	stdev	BaP CF	BaP Eqiv	BaP Stdev
PAH-double extraction								
NAPHTH	2290.00	2310.00	1710.00	2103.33	340.78			
ACENAY	**18.00**	**17.00**	**18.00**	17.67	0.58			
ACENAP	993.00	1050.00	786.00	943.00	138.92			
FLUORE	1000.00	1090.00	808.00	966.00	144.04			
PHENAN	3570.00	3820.00	2920.00	3436.67	464.58			
ANTRAC	1470.00	1870.00	1130.00	1490.00	370.41			
FLANTHE	1750.00	1900.00	1410.00	1686.67	251.06			
PYRENE	1190.00	1260.00	1010.00	1153.33	128.97			
CHRYSE	302.00	337.00	257.00	298.67	40.10	0.00	0.30	0.04
BAANTHR	279.00	302.00	237.00	272.67	32.96	0.10	27.27	3.30
BBFLANT	96.50	103.00	82.20	93.90	10.64	0.10	9.39	1.06
BKFLANT	87.90	91.10	72.70	83.90	9.83	0.01	0.84	0.10
BAPYRE	67.60	71.10	59.80	66.17	5.78	1.00	66.17	5.78
I123PYR	**29.00**	30.00	21.00	26.67	4.93	0.10	2.67	0.49
DBAHANT	<30	<30	<30	0.00	0.00	1.00	0.00	0.00
B-GHI-PY	**20.00**	**21.00**	**18.00**	19.67	1.53			
2MeNAPH	860.00	860.00	629.00	783.00	133.37			
PCP	1410.00	1320.00	1530.00	1420.00	105.36			
Total PAH	14023.00	15132.20	11168.70	13441.30	2044.78			
Total BaP							106.63	

SAMPLE DAY 0 6-Jul-98

LTU 1 — **Physical Characterization**

Replicate	1	2	3	4	5	6	7	avg	stdev
FMC %									
Pan (g)	11.6	11.8	11.8	11.8	11.8				
Pan& Wet Soil (g)	75.23	33.05	91.86	119.32	117.29				
Wet Soil (g)	63.63	21.25	80.06	107.52	105.49				
Pan + Dry Soil (g)	62.6	29.3	77.1	100.3	98.0				
Dry Soil (g)	51.0	17.5	65.3	88.5	86.2				
FMC %	24.8%	21.4%	22.6%	21.5%	22.4%			22.5%	1.4%
MOISTURE %	15.3	14.0	14.5					14.6	0.7
TVS %	7.9	1.5	7.5					5.6	3.6
pH	8.97	9.11	9.1	8.85	9.12			9.03	0.12
Atterburg Limits									
liquid limit	23	21	23	24	23	22	24	23	1.07
plastic limit	17	16	16	16	18	17	18	17	0.90
plasticity index	6	5	7	8	5	5	6	6	1.15
soil type	CL-ML	CL-ML	CL	CL	CL-ML	CL-ML	CL-ML		
PSD									
% Gravel	0	0	0	0	0	0	0	0	0
% Sand	52.26	16.43	42.23	40.88	36.94	20.88	17.74	32.48	14.06
% Fines	47.74	83.57	57.77	59.12	63.06	79.12	82.26	67.52	14.06
METALS, mg/kg									
PB	11.9	11.4	11.3	14.2	11.5	12.9	17	12.89	2.09
NI	11.6	10.9	12.8	11.1	10.2	10.9	10.5	11.14	0.85
ZN	38.6	32.3	33.3	33.3	39.1	31.9	31.8	34.33	3.15
FE	8360	10400	10800	12100	11500	10200	9840	10457.14	1118.18
FE-2	<17	<15	16.5	<17	27.7	<17	<17	22.10	7.92
FE-3	8360	10400	10800	12100	11500	9940	9840	10420.00	1220.93
MG	4100	3630	3700	4180	3560	3520	3690	3768.57	262.83
MN	47.2	46.4	44.4	49.2	41.4	45.5	44.9	45.57	2.44
AS	5.2	5	5.2	6.1	4.8	4.9	4.8	5.14	0.45
BA	742	656	664	759	645	639	673	682.57	48.00
CD	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.00	0.00
CR	17.5	17.2	20.5	17.8	15.8	18.5	16.2	17.64	1.56
HG	0.4	0.346	0.37	0.502	0.331	0.396	0.376	0.39	0.06
SE	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.00	0.00

SAMPLE DAY 0	6-Jul-98								
LTU 2				Physical Characterization					
Replicate	1	2	3	4	5	6	7	avg	stdev
EMC %	18.7	17	17.6	14.3	19.9			17.5	2.1
MOISTURE %	13.0	14.6	14.4					14	0.9
TVS %	6	4.4	9					6.5	2.3
pH	8.78	8.82	8.88	8.78	8.46			8.74	0.16
Atterburg Limits									
liquid limit	25	27	27	26	27	27	26	26	0.79
plastic limit	17	16	16	16	18	17	18	17	0.90
plasticity index	8	11	11	10	9	10	8	10	1.27
soil type	CL	CL	CL	CL	CL	CL	CL		
PSD									
% Gravel	0	0	0	0	0	0	0	0	0
% Sand	31.5	34.95	33.72	2.79	40.22	27.03	0	24.32	16.17
% Fines	68.5	65.05	66.28	97.21	59.78	72.97	100	75.68	16.17
METALS, mg/kg									
PB	14.2	12.1	12.9	12.3	12.3	15.2	12.2	13.03	1.21
NI	12.1	10.2	11.2	10.5	10.6	10	10.1	10.67	0.75
ZN	35.8	34.9	33.6	33.9	34.9	34	32	34.16	1.21
FE	11600	9810	9850	10000	10800	10600	9940	10371.43	665.39
FE-2	<14	<14	<14	<14	<14	<14	<17	0.00	0.00
FE-3	11600	9810	9850	10000	10800	10600	9940	10371.43	665.39
MG	4090	3490	3840	3690	3720	3440	3540	3687.14	226.69
MN	47.7	46.1	47.2	44.4	44.7	41.8	43.4	45.04	2.10
AS	5.3	4.7	4.7	5	5.1	4.9	4.8	4.93	0.22
BA	741	638	710	674	680	626	645	673.43	41.35
CD	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.00	0.00
CR	19.4	15.8	16.8	16.3	16.4	15.7	15.6	16.57	1.32
HG	0.374	0.41	0.393	0.416	0.348	0.347	0.357	0.38	0.03
SE	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.00	0.00

SAMPLE DAY 14	Contaminant Concentration, mg/kg, and Physical Analysis											
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Eqiv.	BaP Stdev
PAH												
NAPHTH	2290	2130	1930	2050	2080	2120	1950	2078.57	121.44			
ACENAY	<290	<300	<290	<290	<290	<290	<300	0	0			
ACENAP	1010	971	885	916	949	962	950	949	39.92			
FLUORE	1090	1020	940	999	1050	1030	1090	1031.29	52.84			
PHENAN	3590	3450	3330	3370	3470	3450	3560	3460	93.27			
ANTRAC	1830	1220	1240	1310	1730	1530	1630	1498.57	245.52			
FLANTHE	1660	1680	1670	1640	1670	1660	1770	1678.57	42.20			
PYRENE	1150	1100	1110	1090	1050	1100	1070	1095.71	31.55			
CHRYSE	297	**292**	**288**	291	298	**283**	**284**	290.43	5.86	0.001	0.29	0.01
BAANTHR	**253**	**253**	**240**	**243**	**249**	**251**	**246**	247.86	5.05	0.1	24.79	0.50
BBFLANT	**89.8**	**109**	**96.2**	**102**	**107**	**96.9**	**97.7**	99.8	6.67	0.1	9.98	0.67
BKFLANT	**114**	**97.3**	**117**	**102**	**99.6**	**110**	**113**	107.56	7.81	0.01	1.08	0.08
BAPYRE	**68.4**	**83.8**	**78.9**	**72.1**	**75.7**	**65.1**	**79.5**	74.79	6.62	1	74.79	6.62
I123PYR	<290	<300	<290	<290	<290	<290	<300			0.1	0	0.00
DBAHANT	<290	<300	<290	<290	<290	<290	<300			1	0	0.00
B-GHI-PY	<290	<300	<290	<290	<290	<290	<300					
2MeNAPH	828	804	712	754	772	770	775	773.57	36.70			
PCP	**578**	2060	1880	1950	1920	1720	1850	1708.29	508.95			
TOTAL PAH	14270.2	13210.1	12637.1	12939.1	13600.3	13428	13615.2	13385.71	528.13			
TOTAL BaP											110.92	
MOISTURE %	9.5	13.6	9.1	25	53.6	13.6	60	26.34	21.54			

Sample Day 28	Contaminant Concentration, mg/kg, and Physical Analysis											
3-Aug-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	ave	stdev	BaP CF	BaP Eqiv.	BaP Stdev
PAH												
NAPHTH	1560	1475	1680	1410	1410	1660	1198	1484.7	167.33			
ACENAY	<290	<290	<290	<290	<290	<290	<290					
ACENAP	949	950	965	902	903	927	873	924.1	32.96			
FLUORE	1020	1040	1060	979	1010	1000	966	1010.7	32.90			
PHENAN	3500	3520	3580	3250	3300	3460	3226	3405.1	143.17			
ANTRAC	1590	1480	1410	1330	1750	1390	1559	1501.3	143.51			
FLANTHE	1760	1790	1810	1590	1610	1680	1569	1687.0	153.09			
PYRENE	1230	1270	1330	1170	1160	1260	1138	1222.6	69.62			
CHRYSE	318	364	337	299	306	320	295	319.9	24.12	0.001	0.320	0.02
BAANTHR	**282**	295	**282**	**263**	**267**	**271**	**251**	**273.0**	14.55	0.1	27.3	1.45
BBFLANT	**84.4**	**88.9**	**89.4**	**77.2**	**81.3**	**85.4**	**92**	**85.5**	5.11	0.1	8.55	0.51
BKFLANT	**109**	**119**	**116**	**112**	**109**	**104**	**94**	**109.0**	8.25	0.01	1.09	0.08
BAPYRE	**64.8**	**70.5**	**75.4**	**69.7**	**72.3**	**65**	**65.3**	**69.0**	4.12	1	69	4.12
I123PYR	<290	<290	<290	<290	<290	<290	<290			0.1		0.00
DBAHANT	<290	<290	<290	<290	<290	<290	<290			1		0.00
B-GHI-PY	<290	<290	<290	<290	<290	<290	<290					
2MeNAPH	772	758	783	716	727	721	683	737.1	35.34			
Total PAH	13239.2	13220.4	13517.8	12167.9	12705.6	12943.4	12009.3	12829.1	567.62			
PCP	2330	2430	2340	2060	2200	1900	2040	2185.7	192.86			
TOTAL BaP											106.261	
moisture %	15.4	14.74	14.76	14.63	14.56			14.82	0.34			
pH	8.56	8.34	8.41	8.52	8.68			8.5	0.1			
NUTRIENTS, mg/kg												
TOC	33700	31900	25600	24800	24400	26600	30600	28228.6	3764.2			
TKN	349	465	504	404	311	344	332	387.0	73.2			
TP	591	1112	710	589	565	538	591	670.9	201.8			

Sample Day 28	Contaminant Concentration, mg/kg, and Physical Analysis											
3-Aug-98												
LTU 2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	1397.00	1434.00	830.00	1167.00	1277.00	1020.00	837.00	1137.43	249.75			
ACENAY	<290	<290	<290	<290	<290	<290	<290	0.00	0.00			
ACENAP	884.00	917.00	745.00	878.00	894.00	896.00	899.00	873.29	57.90			
FLUORE	987.00	981.00	812.00	941.00	998.00	1007.00	998.00	960.57	68.96			
PHENAN	3451.00	3365.00	2757.00	3304.00	3301.00	3338.00	3328.00	3263.43	229.04			
ANTRAC	1567.00	1315.00	1300.00	1329.00	1376.00	1586.00	1355.00	1404.00	120.58			
FLANTHE	1651.00	1587.00	1343.00	1584.00	1641.00	1666.00	1686.00	1594.00	117.09			
PYRENE	1245.00	1190.00	974.00	1227.00	1191.00	1183.00	1342.00	1193.14	111.16			
CHRYSE	328.00	316.00	263.00	306.00	298.00	316.00	315.00	306.00	21.13	0.00	0.31	0.02
BAANTHR	**280.00**	**268.00**	**221.00**	**250.00**	**262.00**	**278.00**	**271.00**	261.43	20.49	0.10	26.14	2.05
BBFLANT	**92.70**	**80.00**	**73.20**	**89.80**	**79.20**	**94.90**	**89.90**	85.67	8.16	0.10	8.57	0.82
BKFLANT	**103.00**	**116.00**	**85.30**	**99.70**	**112.00**	**104.00**	**102.00**	103.14	9.80	0.01	1.03	0.10
BAPYRE	**67.30**	**69.60**	**57.40**	**64.00**	**68.80**	**68.90**	**71.80**	66.83	4.79	1.00	66.83	4.79
I123PYR	<290	<290	<290	<290	<290	<290	<290	0.00	0.00	0.10	0.00	0.00
DBAHANT	<290	<290	<290	<290	<290	<290	<290	0.00	0.00	1.00	0.00	0.00
B-GHI-PY	<290	<290	<290	<290	<290	<290	<290	0.00	0.00			
2MeNAPH	683.00	711.00	560.00	664.00	684.00	676.00	625.00	657.57	50.27			
Total PAH	12736.00	12349.60	10020.90	11903.50	12182.00	12233.80	11919.70	11906.50	877.79			
Total BaP											102.88	
PCP	2079.00	1943.00	1766.00	1885.00	1783.00	2093.00	2115.00	1952.00	147.37			
MOISTURE %	14.81	15.39	13.77	13.97	13.12			14.21	0.89			
pH	8.53	8.45	8.21	8.4	8.21			8.36	0.14			
NUTRIENTS, mg/kg												
TOC	32300.00	30400.00	26400.00	32300.00	25300.00	28700.00	28400.00	29114.29	2724.84			
TKN	298.00	258.00	221.00	392.00	415.00	364.00	341.00	327.00	71.15			
TP	558.00	540.00	529.00	587.00	755.00	511.00	536.00	573.71	83.45			

SAMPLE DAY 42	Contaminant Concentration, mg/kg, and Physical Analysis											
8-Aug-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	ave	stdev	BaP CF	BaP Eqiv.	BaP Stdev
PAH												
NAPHTH	611	708	778	892	882	1360	1310	934.43	290.71			
ACENAY	<290	<290	<290	<290	<290	<290	<290	0.00	0.00			
ACENAP	957	896	858	875	980	916	908	912.86	43.24			
FLUORE	1100	990	940	945	1130	997	995	1013.86	73.39			
PHENAN	3710	3370	3380	3330	3670	3430	3350	3462.86	158.61			
ANTRAC	2100	1850	1670	1550	2000	1670	1380	1745.71	253.17			
FLANTHE	1910	1630	1680	1530	1750	1650	1660	1687.14	118.14			
PYRENE	1430	1270	1340	1210	1300	1230	1220	1285.71	78.92			
CHRYSE	399	340	361	314	352	338	326	347.14	27.64	0.001	0.35	0.03
BAANTHR	323	**284**	290	**266**	308	**287**	**275**	290.43	19.40	0.1	29.04	1.94
BBFLANT	**103**	**116**	**88.6**	**83.1**	**101**	**95**	**93.3**	97.14	10.76	0.1	9.71	1.08
BKFLANT	**107**	**93**	**125**	**99.9**	**114**	**101**	**110**	107.13	10.52	0.01	1.07	0.11
BAPYRE	**83.5**	**70.8**	**83.1**	**67**	**78.3**	**75.9**	**74.2**	76.11	6.10	1	76.11	6.10
I123PYR	<290	<290	<290	<290	<290	<290	<290	0.00	0.00	0.1	0	0.00
DBAHANT	<290	<290	<290	<290	<290	<290	<290	0.00	0.00	1	0	0.00
B-GHI-PY	<290	<290	<290	<290	<290	<290	<290	0.00	0.00			
2MeNAPH	667	663	602	637	756	704	686	673.57	49.14			
TOTAL PAH	13500.5	12280.8	12195.7	11799	13421.3	12853.9	12387.5	12634.10	568.88			
TOTAL BaP											116.29	
PCP	2880	2530	2300	2030	2660	2400	2120	2417.14	299.48			
NUTRIENTS, mg/kg												
TOC	29600	30400	28200	28300	27200	24200	26500	27771.43	2058.09			
TKN	430	430	387	442	429	398	413	418.43	19.87			
TP	559	537	485	585	544	513	503	532.29	34.44			
% MOISTURE	14.71	10.89	9.88	9.37	12.95	10.98	11.44	11.46	1.83			
pH	7.91	8.29	8.13	8.21	8.25	8.15	8.37	8.19	0.15			

SAMPLE DAY 42	Contaminant Concentration, mg/kg, and Physical Analysis											
8-Aug-98												
LTU-2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	474.00	687.00	438.00	354.00	283.00	390.00	630.00	465.14	146.28			
ACENAY	<290	<280	<290	<270	<280	<280	<280	0.00	0.00			
ACENAP	955.00	928.00	903.00	890.00	926.00	838.00	959.00	914.14	41.87			
FLUORE	1040.00	1030.00	984.00	984.00	1050.00	925.00	1090.00	1014.71	54.35			
PHENAN	3580.00	3600.00	3350.00	3440.0	3530.00	3120.00	3600.00	3460.00	176.35			
ANTRAC	1660.00	1870.00	1310.00	1260.00	1670.00	1270.00	1680.00	1531.43	246.13			
FLANTHE	1690.00	1790.00	1780.00	1680.00	1720.00	1580.00	1800.00	1720.00	78.53			
PYRENE	1290.00	1250.00	1300.00	1240.00	1240.00	1150.00	1310.00	1254.29	54.42			
CHRYSE	364.00	350.00	317.00	348.00	343.00	302.00	341.00	337.86	21.18	0.00	0.34	0.02
BAANTHR	307.00	303.00	**286.00**	290.00	291.00	**267.00**	296.00	291.43	13.07	0.10	29.14	1.31
BBFLANT	**109.00**	**111.00**	**93.20**	**110.00**	**106.00**	**101.00**	**108.00**	105.46	6.33	0.10	10.55	0.63
BKFLANT	**107.00**	**108.00**	**112.00**	**100.00**	**101.00**	**91.10**	**104.00**	103.30	6.79	0.01	1.03	0.07
BAPYRE	**82.30**	**77.30**	**73.20**	**81.00**	**70.50**	**70.90**	**74.70**	75.70	4.68	1.00	75.70	4.68
I123PYR	<290	<280	<290	<270	<280	<280	<280	0.00	0.00	0.10	0.00	0.00
DBAHANT	<290	<280	<290	<270	<280	<280	<280	0.00	0.00	1.00	0.00	0.00
B-GHI-PY	<290	<280	<290	<270	<280	<280	<280	0.00	0.00			
2MeNAPH	651.00	608.00	602.00	575.00	583.00	530.00	638.00	598.14	40.63			
TOTAL PAH	12309.30	12712.30	11548.40	11352.00	11913.50	10635.00	12630.70	11871.60	750.55			
TOTAL BaP											116.76	
PCP	2690.00	2810.00	2720.00	2520.00	2570.00	2230.00	2610.00	2592.86	187.32			
NUTRIENTS, mg/kg												
TOC	27400	30500	26500	26400	27900	24800	28600	27442.86	1819.21			
TKN	345	415	429	356	388	419	457	401.29	40.35			
TP	560	536	489	460	513	471	494	503.29	35.56			
% MOISTURE	12.20	10.53	10.95	10.01	11.26	10.98	11.96	11.13	0.77			
pH	8.10	7.89	8.15	7.98	8.06	8.13	8.35	8.09	0.14			

SAMPLE DAY 56	Contaminant Concentration, mg/kg, and Physical Analysis											
2-Sep-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	316.00	445.00	705.00	771.00	744.00	793.00	582.00	622.29	182.47			
ACENAY	<300	<300	<300	<290	<290	<300	<300	0.00	0.00			
ACENAP	761.00	815.00	876.00	871.00	875.00	896.00	895.00	855.57	49.69			
FLUORE	846.00	910.00	956.00	925.00	950.00	983.00	954.00	932.00	44.56			
PHENAN	2840.00	3180.00	3280.00	3340.00	3170.00	3340.00	3360.00	3215.71	182.74			
ANTRAC	1190.00	1560.00	1290.00	1280.00	1170.00	1680.00	1690.00	1408.57	227.70			
FLANTHE	1350.00	1570.00	1610.00	1660.00	1600.00	1590.00	1570.00	1564.29	99.31			
PYRENE	1090.00	1180.00	1230.00	1220.00	1180.00	1170.00	1250.00	1188.57	52.73			
CHRYSE	**279.00**	**297.00**	307.00	330.00	303.00	325.00	336.00	311.00	20.34	0.00	0.31	0.02
BAANTHR	**238.00**	**274.00**	**275.00**	**280.00**	**270.00**	**275.00**	**274.00**	269.43	14.16	0.10	26.94	1.42
BBFLANT	**93.70**	**98.20**	**82.30**	**104.00**	**88.20**	**103.00**	**97.00**	95.20	7.83	0.10	9.52	0.78
BKFLANT	**92.20**	**104.00**	**86.40**	**103.00**	**99.80**	**88.80**	**90.70**	94.99	7.15	0.01	0.95	0.07
BAPYRE	**67.00**	**71.90**	**59.00**	**71.20**	**68.90**	**65.10**	**67.70**	67.26	4.34	1.00	67.26	4.34
I123PYR	<300	<300	<300	<290	<290	<300	<300	0.00	0.00	0.10	0.00	0.00
DBAHANT	<300	<300	<300	<290	<290	<300	<300	0.00	0.00	1.00	0.00	0.00
B-GHI-PY	<300	<300	<300	<290	<290	<300	<300	0.00	0.00			
2MeNAPH	511.00	584.00	603.00	625.00	631.00	585.00	467.00	572.29	60.98			
TOTAL PAH	9673.90	11089.10	11359.70	11580.20	11149.90	11893.90	11633.40	11197.16	728.37			
TOTAL BaP EQUIV											104.98	
PCP	1900.00	2200.00	2320.00	2180.00	2170.00	2080.00	1800.00	2092.86	182.46			
NUTRIENTS, mg/kg												
TOC	31300	32600	32200	19700	20500	27700	25100	27014.29	5424.15			
TKN	419	524	381	456	370	470	403	431.86	54.68			
TP	570	568	530	499	444	558	491	522.86	47.17			
% Moisture	0.17	15.46	15.62	14.28	15.18	15.32	15.86	13.13	5.74			
pH	8.26	8.46	8.25	8.23	8.21	7.92	8.1	8.20	0.16			

SAMPLE DAY 56	Contaminant Concentration, mg/kg, and Physical Analysis											
2-Sep-98												
LTU-2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	437	**275**	**266**	**109**	**113**	389	632	317.29	186.21			
ACENAY	<290	<280	<280	<280	<280	<290	<300	0.00	0.00			
ACENAP	798	820	902	837	807	850	966	854.29	60.07			
FLUORE	860	914	997	953	921	942	1020	943.86	53.47			
PHENAN	3010	3260	3460	3340	3210	3150	3600	3290.00	196.98			
ANTRAC	1100	1500	1480	1680	1550	1350	1320	1425.71	187.78			
FLANTHE	1490	1660	1770	1660	1560	1600	1770	1644.29	104.06			
PYRENE	1140	1180	1230	1230	1200	1130	1310	1202.86	61.57			
CHRYSE	313	325	349	342	305	293	356	326.14	23.75	0.001	0.33	0.02
BAANTHR	**264**	**275**	291	**279**	**272**	**269**	295	277.86	11.41	0.1	27.79	1.14
BBFLANT	**89.4**	**94.8**	**108**	**90.8**	**86**	**93.9**	**97.3**	94.31	7.10	0.1	9.43	0.71
BKFLANT	**90.9**	**82.2**	**97.2**	**107**	**99.7**	**91**	**114**	97.43	10.70	0.01	0.97	0.11
BAPYRE	**67.3**	**59.7**	**76.9**	**69.9**	**68.5**	**68.6**	**70.8**	68.81	5.10	1	68.81	5.10
I123PYR	<290	<280	<280	<280	<280	<290	<300	0.00	0.00	0.1	0.00	0.00
DBAHANT	<290	<280	<280	<280	<280	<290	<300	0.00	0.00	1	0	0
B-GHI-PY	<290	<280	<280	<280	<280	<290	<300	0.00	0.00			
2MeNAPH	420	491	413	440	519	625	<0.50	484.67	80.28			
TOTAL PAH	10079.60	10936.70	11440.10	11137.70	10711.20	10851.50	11551.10	10958.27	493.42			
Total BaP											107.33	
PCP	1800.00	2440.00	2640.00	2490.00	2230.00	2340.00	2600.00	2362.86	285.82			
NUTRIENTS, mg/kg												
TOC	22200	25200	27300	22500	21900	19600	22400	23014.29	2494.95			
TKN	556	446	439	384	463	423	411	446.00	54.83			
TP	555	519	483	450	505	618	606	533.71	62.45			
% MOISTURE	16.66	11.87	12	10.54	8.36	13.4	15.29	12.59	2.81			
pH	8.01	7.98	7.97	7.9	7.92	7.94	8.03	7.96	0.05			

Sample Day 70	Contaminant Concentration, mg/kg, and Physical Analysis										
14-Sep-98											
LTU 1											
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	527	468	475	540	839	558	501	558.29	128.12			
ACENAY	<300	<300	<300	<300	<300	<300	<300	0.00	0.00			
ACENAP	830	797	836	904	877	711	906	837.29	68.77			
FLUORE	944	864	907	986	933	759	1020	916.14	85.85			
PHENAN	3250	3120	3160	3560	3340	2700	3520	3235.71	289.59			
ANTRAC	1910	1290	1310	1460	1380	1140	1510	1428.57	244.37			
FLANTHE	1540	1590	1590	1750	1710	1320	1640	1591.43	140.17			
PYRENE	1000	955	965	1060	1050	847	1140	1002.43	93.38			
CHRYSE	**270**	**275**	**261**	**294**	**280**	**218**	**285**	269.00	24.85	0.001	0.27	0.02
BAANTHR	**226**	**230**	**232**	**250**	**236**	**195**	**254**	231.86	19.29	0.1	23.19	1.93
BBFLANT	**102**	**96**	**91.8**	**103**	**94.9**	**72.8**	**108**	95.50	11.43	0.1	9.55	1.14
BKFLANT	**97.5**	**101**	**107**	**112**	**110**	**87.3**	**101**	102.26	8.43	0.01	1.02	0.08
BAPYRE	**70.4**	**73.1**	**75.3**	**72.3**	**75.4**	**65.4**	**72.1**	72.00	3.41	1	72.00	3.41
I123PYR	<300	<300	<300	<300	<300	<300	<300	0.00	0.00	0.1	0.00	0.00
DBAHANT	<300	<300	<300	<300	<300	<300	<300	0.00	0.00	1	0.00	0.00
B-GHI-PY	<300	<300	<300	<300	<300	<300	<300	0.00	0.00			
2MeNAPH	555	539	528	570	641	484	590	558.14	49.67			
TOTAL PAH	11321.9	10398.1	10538.1	11661.3	11566.3	9157.5	11647.1	10898.61	929.06			
TOTAL BaP											106.03	
PCP	2650	2390	2380	2630	2610	1800	2190	2378.57	305.75			
% Moisture	19.05	16.09	17.12	15.23	15.37	15.95	15.96	16.40	1.32			
NUTRIENTS, mg/kg												
TOC	30800	28400	31100	31000	28600	28200	29600	29671.4	1291.92			
TKN	598	395	405	387	296	435	414	418.57	90.60			
TP	559	523	486	495	460	568	529	517.14	39.24			

Sample Day 70	Contaminant Concentrations, mg/kg, and Physical Analysis											
14-Sep-98												
LTU-2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	**299**	311	**163**	**71.5**	**112**	529	**215**	242.93	154.55			
ACENAY	<300	<290	<280	<280	<280	<280	<300	0.00	0.00			
ACENAP	964	881	799	783	773	877	846	846.14	67.84			
FLUORE	1060	1000	890	866	887	960	920	940.43	70.22			
PHENAN	3720	3400	3090	3180	3280	3260	3180	3301.43	208.68			
ANTRAC	1650	1550	1460	1520	1510	1450	1460	1514.29	70.44			
FLANTHE	1830	1690	1550	1590	1630	1540	1650	1640.00	99.50			
PYRENE	1140	1080	949	978	1030	1040	988	1029.29	65.48			
CHRYSE	309	**276**	**257**	**259**	**269**	**256**	**280**	272.29	18.74	0.001	0.27	0.02
BAANTHR	**268**	**242**	**223**	**229**	**237**	**236**	**231**	238.00	14.58	0.1	23.80	1.46
BBFLANT	**98.2**	**100**	**90.7**	**88.9**	**87.8**	**102**	**86.7**	93.47	6.38	0.1	9.35	0.64
BKFLANT	**129**	**105**	**99**	**103**	**108**	**94.2**	**101**	105.60	11.22	0.01	1.06	0.11
BAPYRE	**80.5**	**77.3**	**68.9**	**69.7**	**77.6**	**81.2**	**73.7**	75.56	4.93	1	75.56	4.93
I123PYR	<300	<290	<280	<280	<280	<280	<300	0.00	0.00	0.1	0.00	0.00
DBAHANT	<300	<290	<280	<280	<280	<280	<300	0.00	0.00	1	0.00	0.00
B-GHI-PY	<300	<290	<280	<280	<280	<280	<300	0.00	0.00			
2MeNAPH	508	451	306	345	338	493	395	405.14	80.06			
Total PAH	12055.7	11163.3	9945.6	10083.1	10339.4	10918.4	10426.4	10704.56	736.51			
Total BaP											110.03	
PCP	2670	2550	2150	2370	2420	1670	2360	2312.86	326.74			
% Moisture	17.13	13.19	12.12	8.81	11.35	13.45	15.67	13.10	2.75			
NUTRIENTS, mg/kg												
TOC	33800	30100	28000	30400	20000	29100	28500	28557.14	4224.87			
TKN	704	411	381	286	280	303	299	380.57	151.25			
TP	739	538	525	487	486	435	534	534.86	96.98			

Sample Day 84	Contaminant Concentrations, mg/kg, and Physical Analysis											
28-Sep-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	150	**76.8**	**74.2**	**122**	460	**78.9**	**136**	156.84	137.18			
ACENAY	<150	<150	<150	<155	<145	<150	<150	0.00	0.00			
ACENAP	865	610	913	649	845	902	922	815.14	130.13			
FLUORE	846	633	868	716	885	925	915	826.86	110.08			
PHENAN	2810	2440	3180	2630	3150	3220	3470	2985.71	367.28			
ANTRAC	1270	901	1680	1250	1110	1250	1360	1260.14	237.37			
FLANTHE	1540	1400	1800	1450	1640	1650	1600	1582.86	134.25			
PYRENE	914	867	1100	904	1160	1080	1290	1045.00	156.11			
CHRYSE	238	221	282	227	251	260	307	255.14	30.83	0.001	0.26	0.03
BAANTHR	214	177	247	191	223	237	271	222.86	32.40	0.1	22.29	3.24
BBFLANT	**81.2**	**77.3**	**105**	**79.3**	**97.8**	**101**	**116**	93.94	14.87	0.1	9.39	1.49
BKFLANT	**82.8**	**69.3**	**107**	**85.2**	**91.5**	**91**	**119**	92.26	16.33	0.01	0.92	0.16
BAPYRE	**60.9**	**49.8**	**77.5**	**55.5**	**72.8**	**75.8**	**83.8**	68.01	12.66	1	68.01	12.66
I123PYR	<150	<150	<150	<155	<145	<150	<150	0.00	0.00	0.1	0.00	0.00
DBAHANT	<150	<150	<150	<155	<145	<150	<150	0.00	0.00	1	0.00	0.00
B-GHI-PY	<150	<150	<150	<155	<145	<150	<150	0.00	0.00			
2MeNAPH	176	188	188	220	393	261	311	248.14	79.93			
Total PAH	9247.90	7710.20	10621.70	8579.00	10379.10	10131.70	10900.80	9652.91	1179.25			
Total BaP											100.87	
PCP	1620	1600	2280	1800	2400	2690	2580	2138.57	458.42			
NUTRIENTS, mg/kg												
TOC	26400	29000	37300	27500	28800	26300	21500	28114.29	4760.75			
TKN	4867	9200	7800	8600	3300	6933	7200	6842.86	2087.71			
% Moisture	16.12	15.8	14.45	13.6	14.27	13.95	14.31	14.64	0.95			
pH	7.56	7.20	7.31	7.30	7.52	7.25	7.52	7.38	0.15			
PSD												
% Gravel	0	0	0	0	0	0	0	0	0			
% Sand	47.12	32.42	48.9	53.28	41.67	46.57	50.75	45.82	6.93			
% Fines	52.88	67.58	51.1	46.72	58.33	53.43	49.25	54.18	6.93			

Sample Day 84	Contaminant Concentrations, mg/kg, and Physical Analysis										
28-Sep-98											
LTU-2											
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	**47.1**	425	**71.4**	157	**32.6**	230	209	167.44	137.82			
ACENAY	<150	<150	<145	<150	<140	<145	<140	0.00	0.00			
ACENAP	867	845	820	875	813	855	846	845.86	22.84			
FLUORE	916	855	859	929	844	948	896	892.43	40.53			
PHENAN	3390	3270	3250	3500	3230	3540	3330	3358.57	123.08			
ANTRAC	1280	1450	1320	1350	1520	1910	1770	1514.29	240.06			
FLANTHE	1700	1710	1740	1910	1690	1810	1690	1750.00	82.26			
PYRENE	1140	1030	1040	1100	1020	1200	1050	1082.86	67.01			
CHRYSE	289	272	287	301	280	295	281	286.43	9.76	0.001	0.29	0.01
BAANTHR	250	241	245	260	245	256	246	249.00	6.78	0.1	24.90	0.68
BBFLANT	**107**	**99.7**	**95.3**	**116**	**103**	**111**	**108**	105.71	6.98	0.1	10.57	0.70
BKFLANT	**95.1**	**78.9**	**108**	**110**	**98.7**	**107**	**93.5**	98.74	10.92	0.01	0.99	0.11
BAPYRE	**81.1**	**70.9**	**77.8**	**83.1**	**77.8**	**84.2**	**71.1**	78.00	5.36	1	78.00	5.36
I123PYR	<150	<150	<145	<150	<140	<145	<140	0.00	0.00	0.1	0.00	0.00
DBAHANT	<150	<150	<145	<150	<140	<145	<140	0.00	0.00	1	0.00	0.00
B-GHI-PY	<150	<150	<145	<150	<140	<145	<140	0.00	0.00			
2MeNAPH	209	300	**77.2**	225	143	263	201	202.60	74.11			
TOTAL PAH	10371.3	10647.5	9990.7	10916.1	10097.1	11609.2	10791.6	10631.93	551.77			
TOTAL BaP											114.75	6.85
PCP	2670	2950	2740	3330	2570	1980	2600	2691.43	409.61			
NUTRIENTS, mg/kg												
TOC	23700	16400	27600	25100	26800	27800	24000	24485.71	3929.56			
TKN	3466	6733	2333	6267	966	5733	1033	3790.14	2462.24			
% Moisture	15.02	14.31	13.05	13.98	8.28	13.76	10.77	12.74	2.38			
pH	7.51	7.38	7.41	7.26	7.8	7.33	7.84	7.50	0.23			
PSD												
% Gravel	0	0	0	0	0	0	0	0	0			
% Sand	34.52	45.04	53.06	52.14	48.6	48.65	48.79	47.26	6.20			
% Fines	65.48	54.96	46.94	47.86	51.4	51.35	51.21	52.74	6.20			

Sample Day 98	Contaminant Concentrations, mg/kg, and Physical Analysis											
13-Oct-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv.	BaP Stdev
PAH												
NAPHTH	<150	<150	<150	154	**104**	266	369	223.25	118.44			
ACENAY	<150	<150	<150	<145	<150	<150	<150	0.00	0.00			
ACENAP	882	838	896	879	863	865	859	868.86	18.76			
FLUORE	856	870	912	861	888	835	850	867.43	25.64			
PHENAN	3160	3060	3350	3180	3370	3080	3140	3191.43	122.80			
ANTRAC	1650	1950	1610	1280	1390	1060	1580	1502.86	287.96			
FLANTHE	1760	1630	1710	1730	1760	1660	1820	1724.29	64.51			
PYRENE	1190	1110	1090	1100	1130	1120	1140	1125.71	33.09			
CHRYSE	316	284	281	307	299	287	317	298.71	15.11	0.001	0.30	0.02
BAANTHR	262	251	260	276	264	255	279	263.86	10.32	0.1	26.39	1.03
BBFLANT	**87.6**	**79**	**77**	**92.4**	**76.4**	**74.6**	**93.2**	82.89	7.95	0.1	8.29	0.80
BKFLANT	**85.2**	**89.1**	**94.8**	**83.6**	**94.6**	**87.3**	**89.9**	89.21	4.32	0.01	0.89	0.04
BAPYRE	**59.9**	**63.2**	**58.8**	**66.4**	**63.6**	**61.3**	**71.1**	63.47	4.21	1	63.47	4.21
I123PYR	<150	<150	<150	<145	<150	<150	<150	0.00	0.00	0.1	0.00	0.00
DBAHANT	<150	<150	<150	<145	<150	<150	<150	0.00	0.00	1	0.00	0.00
B-GHI-PY	<150	<150	<150	<145	<150	<150	<150	0.00	0.00			
2MeNAPH	159	167	194	234	154	251	274	204.71	48.30			
Total PAH	10467.7	10391.3	10533.6	10243.4	10456.6	9902.2	10882.2	10411.00	297.13			
Total BaP											99.34	
PCP	2420	2490	2290	2780	2090	2180	2930	2454.29	308.16			
NUTRIENTS, mg/kg												
TOC	27900	23000	22900	25400	25100	25400	24500	24885.71	1698.46			
TKN	774	461	599	377	755	487	668	588.71	152.67			
TP	487	360	453	367	499	227	374	395.29	94.27			
% Moisture	16.03	15.69	15.08	14.79	15.08	15.32	15.82	15.40	0.45			

Sample Day 98	Contaminant Concentrations, mg/kg, and Physical Analysis											
13-Oct-98												
LTU-2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	<150	**46.6**	**74.3**	<145	168	**32**	206	105.38	77.22			
ACENAY	<150	<150	<150	<145	<150	<145	<145	0.00	0.00			
ACENAP	762	760	779	795	784	882	838	800.00	44.60			
FLUORE	722	797	862	846	850	820	736	804.71	56.12			
PHENAN	2630	3120	3180	3270	3280	3000	2720	3028.57	260.67			
ANTRAC	1210	1080	1620	1190	1600	1460	1150	1330.00	224.65			
FLANTHE	1550	1680	1680	1860	1700	1950	1820	1748.57	134.96			
PYRENE	1010	1080	1060	1170	1200	1220	1180	1131.43	80.50			
CHRYSE	265	288	283	329	304	338	322	304.14	26.84	0.001	0.30	0.03
BAANTHR	236	259	251	273	264	291	277	264.43	18.05	0.1	26.44	1.81
BBFLANT	**73.1**	**80.5**	**89.1**	**103**	**89**	**110**	**104**	92.67	13.50	0.1	9.27	1.35
BKFLANT	**75**	**77.2**	**71.5**	**82**	**78.4**	**84.4**	**80.7**	78.46	4.37	0.01	0.78	0.04
BAPYRE	**53**	**59.1**	**59.4**	**68.8**	**65.9**	**73.1**	**75**	64.90	8.07	1	64.90	8.07
I123PYR	<150	<150	<150	<145	<150	<145	<145	0.00	0.00	0.1	0.00	0.00
DBAHANT	<150	<150	<150	<145	<150	<145	<145	0.00	0.00	1	0.00	0.00
B-GHI-PY	<150	<150	<150	<145	<150	<145	<145	0.00	0.00			
2MeNAPH	**127**	**93.9**	**125**	**58.5**	169	**72.3**	190	119.39	48.50			
Total PAH	8713.1	9421.3	10134.3	10045.3	10552.3	10332.8	9698.7	9842.54	625.05			
Total BaP											101.70	
PCP	2180	2480	2490	2560	2490	3060	3020	2611.43	317.20			
NUTRIENTS. mg/kg												
TOC	27200	23700	14100	20500	26000	23800	16700	21714.29	4853.67			
TKN	707	932	780	678	354	497	708	665.14	188.52			
TP	564	505	367	345	281	388	519	424.14	105.21			
% Moisture	15.56	16.75	15.27	14.19	14.99	13.94	14.46	15.02	0.96			

Sample Day 112	Contaminant Concentrations, mg/kg											
10-Oct-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	<145	<145	<140	**66**	251	**95**	350	190.50	133.82			
ACENAY	<145	<145	<140	<145	<145	<145	<145	0.00	0.00			
ACENAP	683	750	703	709	815	714	707	725.86	44.10			
FLUORE	643	742	751	763	855	705	773	747.43	64.83			
PHENAN	2340	2850	2890	2810	3180	2670	3120	2837.14	281.76			
ANTRAC	1460	1450	1250	1270	1380	1300	1460	1367.14	93.04			
FLANTHE	1450	1670	1530	1550	1690	1350	1720	1565.71	136.36			
PYRENE	1070	1210	1120	1020	1240	1020	1250	1132.86	100.62			
CHRYSE	283	320	293	281	306	247	325	293.57	26.71	0.001	0.29	0.03
BAANTHR	237	264	249	243	258	223	273	249.57	17.01	0.1	24.96	1.70
BBFLANT	**87**	**95**	**82**	**86**	**94**	**71**	**95**	87.14	8.75	0.1	8.71	0.87
BKFLANT	**80**	**85**	**91**	**76**	**80**	**75**	**96**	83.29	7.83	0.01	0.83	0.08
BAPYRE	**64**	**69**	**64**	**61**	**67**	**52**	**69**	63.71	5.94	1	63.71	5.94
I123PYR	<145	<145	<140	<145	<145	<145	<145	0.00	0.00	0.1	0.00	0.00
DBAHANT	<145	<145	<140	<145	<145	<145	<145	0.00	0.00	1	0.00	0.00
B-GHI-PY	<145	<145	<140	<145	<145	<145	<145	0.00	0.00			
2MeNAPH	**117**	**114**	**64**	**86**	187	**136**	200	129.14	49.83			
Total PAH	8514	9619	9087	9021	10403	8658	10438	9391.43	786.14			
Total BaP											98.51	
PCP	2540	2790	2650	2440	2650	2150	2640	2551.43	207.32			

Sample Day 112	Contaminant Concentrations, mg/kg											
10-Oct-98												
LTU-2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	<145	<145	<145	<140	<140	<140	**82**	82.00	0.00			
ACENAY	<145	<145	<145	<140	<140	<140	<140	0.00	0.00			
ACENAP	794	719	724	577	682	708	688	698.86	65.10			
FLUORE	732	715	799	631	763	780	777	742.43	57.02			
PHENAN	2620	2720	2920	2490	2900	2800	2910	2765.71	164.91			
ANTRAC	1320	1250	1310	997	1270	1340	1780	1323.86	232.28			
FLANTHE	1770	1650	1610	1370	1420	1660	1510	1570.00	142.71			
PYRENE	1200	1160	1090	916	1090	1110	1080	1092.29	89.20			
CHRYSE	323	296	283	246	284	292	289	287.57	22.77	0.001	0.29	0.02
BAANTHR	278	255	247	211	239	249	247	246.57	19.95	0.1	24.66	1.99
BBFLANT	**88**	**82**	**85**	**68**	**72**	**87**	**81**	80.43	7.63	0.1	8.04	0.76
BKFLANT	**101**	**83**	**74**	**74**	**83**	**78**	**84**	82.43	9.22	0.01	0.82	0.09
BAPYRE	**72**	**60**	**60**	**54**	**55**	**58**	**65**	60.57	6.21	1	60.57	6.21
I123PYR	<145	<145	<145	<140	<140	<140	<140	0.00	0.00	0.1	0.00	0.00
DBAHANT	<145	<145	<145	<140	<140	<140	<140	0.00	0.00	1	0.00	0.00
B-GHI-PY	<145	<145	<145	<140	<140	<140	<140	0.00	0.00			
2MeNAPH	**33**	<145	<145	<140	**93**	**34**	**89**	62.25	33.24			
Total PAH	9331	8990	9202	7634	8951	9196	9682	8998.00	648.37			
Total BaP											94.38	
PCP	2990	2570	2640	2140	2340	2660	2360	2528.57	276.67			

Sample Day 112 10-Oct-98 **LTU 1**	**Physical Analysis**								
Replicate	1	2	3	4	5	6	7	avg	stdev
% Moisture	15.79	13.7	12.36	14.71	13.41	14.16	13.85	14.00	1.07
FMC %	26.6	26.6	25	38.9	25			28.42	5.91
Nutrients, mg/kg									
TOC	26900	24800	26900	21500	29900	24800	25200	25714.3	2582.9
TKN	508	405	386	525	195	268	299	369.43	122.89
TP	440	250	365	443	294	375	415	368.86	73.57
Nutrients-after FMC, mg/kg									
TKN	999	1474	1365	967	1390			1239.00	237.43
TP	358	384	428	427	469			413.20	43.08

Sample Day 112 10-Oct-98 **LTU 2**	**Physical Analysis**								
Replicate	1	2	3	4	5	6	7	avg	stdev
% Moisture	14.27	12.53	12.24	11.67	13.66	12.14	12.71	12.75	0.91
FMC %	25	37	39	25	22			29.60	7.80
Nutrients, mg/kg									
TOC	27300	28400	21500	25800	21900	24800	19700	24200	3240.4
TKN	149	193	323	216	560	169	172	254.57	146.36
TP	402	408	415	400	415	345	391	396.57	24.30
Nutrients-after FMC, mg/kg									
TKN	1067	1114	1336	1263	1140			1184	111.66
TP	349	398	454	446	443			418	44.35

Sample Day 126	Contaminant Concentration, mg/kg, and Physical Analysis											
11-Nov-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	**41**	**36**	**82**	**24**	<120	151	**44**	63.00	47.33			
ACENAY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
ACENAP	787	839	800	890	760	818	690	797.71	62.95			
FLUORE	682	900	782	847	665	842	749	781.00	88.05			
PHENAN	1860	3100	2670	2990	2370	2930	2540	2637.14	430.18			
ANTRAC	1400	1570	1130	1400	1250	1700	1450	1414.29	189.46			
FLANTHE	1720	1730	1600	1870	1620	1630	1400	1652.86	144.88			
PYRENE	1230	1160	1140	1350	1090	1140	974	1154.86	116.27			
CHRYSE	322	323	303	349	300	306	259	308.86	27.66	0.001	0.31	0.03
BAANTHR	276	264	252	297	253	272	225	262.71	22.63	0.1	26.27	2.26
BBFLANT	**100**	**83**	**83**	**96**	**82**	**88**	**77**	87.00	8.25	0.1	8.70	0.82
BKFLANT	**84**	**86**	**97**	**111**	**95**	**88**	**70**	90.14	12.72	0.01	0.90	0.13
BAPYRE	**69**	**70**	**64**	**74**	**64**	**65**	**56**	66.00	5.74	1	66.00	5.74
I123PYR	**28**	<120	<120	**29**	<120	<120	<120	28.50	0.71	0.1	2.85	0.07
DBAHANT	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
2MeNAPH	**83**	**111**	144	**80**	**56**	172	121	109.57	40.14			
Total PAH	8765	10383	9291	10487	8661	10374	8776	9533.86	848.70			
Total BaP											105.03	
PCP	2850	3100	2720	3180	2710	2690	2260	2787.14	303.85			
Nutrients, mg/kg												
TOC	28400	23000	27200	27600	24600	23700	23500	25428.6	2235.11			
TKN	579	681	579	711	443	642	581	602.29	88.04			
TP	557	517	560	512	582	436	410	510.57	65.09			
% Moisture	42.9	40.8	40.8	42.9	38.9		42.9	41.53	1.65			
pH	7.63	7.7	7.64	7.59	7.7	7.44	7.52	7.60	0.10			

Sample Day 126	Contaminant Concentration, mg/kg, and Physical Analysis											
11-Nov-98												
LTU 2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	**33**	<120	232	**64**	<120	**35**	<120	91.00	95.06			
ACENAY	<120	<120	<120	<110	<120	<120	<120	0.00	0.00			
ACENAP	862	786	903	794	664	804	724	791.00	80.01			
FLUORE	925	777	956	883	650	814	680	812.14	117.93			
PHENAN	3260	2780	3490	3110	2350	2970	2350	2901.43	437.05			
ANTRAC	1370	1470	1510	1470	1300	1400	1520	1434.29	80.59			
FLANTHE	1790	1680	1880	1750	1450	1730	1600	1697.14	139.49			
PYRENE	1230	1200	1300	1180	1010	1200	1110	1175.71	92.53			
CHRYSE	321	317	336	322	265	317	286	309.14	24.61	0.001	0.31	0.02
BAANTHR	285	276	302	272	232	277	258	271.71	22.01	0.1	27.17	2.20
BBFLANT	**102**	**87**	**100**	**98**	**73**	**90**	**85**	90.71	10.23	0.1	9.07	1.02
BKFLANT	**82**	**90**	**92**	**93**	**69**	**97**	**81**	86.29	9.59	0.01	0.86	0.10
BAPYRE	**75**	**65**	**72**	**67**	**60**	**66**	**61**	66.57	5.44	1	66.57	5.44
I123PYR	<120	**24**	**25**	**27**	<120	<120	<120	25.33	1.53	0.1	2.53	0.15
DBAHANT	<120	<120	<120	<110	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<110	<120	<120	<120	0.00	0.00			
2MeNAPH	154	**45**	199	**60**	<120	**50**	**30**	89.67	69.43			
Total PAH	10489	9597	11397	10190	8123	9850	8785	9775.86	1084.70			
Total BaP											106.52	
PCP	3090	2530	2670	2980	2210	2740	2510	2675.71	298.32			
Nutrients, mg/kg												
TOC	24400	22400	21000	23900	22600	23200	23600	23014.29	1132			
TKN	679	544	778	741	634	588	672	662.29	81.92			
TP	535	484	489	485	510	465	516	497.71	23.70			
% Moisture	40.8	38.9	38.9	40.8	42.9	26.6	25	36.27	7.30			
pH	7.49	7.56	7.48	7.32	7.31	7.45	7.45	7.44	0.09			

Sample Day 140	Contaminant Concentrations, mg/kg, and Physical Analysis										
24-Nov-98											
LTU 1											
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	195	45	58	105	142	491	<120	172.67	165.41			
ACENAY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
ACENAP	806	841	787	721	808	756	686	772.14	54.30			
FLUORE	836	805	814	787	877	830	718	809.57	49.32			
PHENAN	2920	2870	2880	3000	3050	2960	2560	2891.43	159.63			
ANTRAC	1280	1330	1130	1310	1270	1280	1370	1281.43	75.37			
FLANTHE	1620	1720	1510	1620	1580	1520	1410	1568.57	99.40			
PYRENE	1100	1180	1030	1140	1100	987	1050	1083.86	66.26			
CHRYSE	301	317	276	304	303	272	268	291.57	19.16	0.001	0.29	0.02
BAANTHR	255	260	235	261	260	228	215	244.86	18.69	0.1	24.49	1.87
BBFLANT	93	87	90	86	92	83	82	87.57	4.28	0.1	8.76	0.43
BKFLANT	84	102	68		84	76	71	80.83	12.27	0.01	0.81	0.12
BAPYRE	63	72	60	68	61	56	52	61.71	6.80	1	61.71	6.80
I123PYR	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	0.1	0.00	0.00
DBAHANT	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
2MeNAPH	167	94	127	100	171	321	60	148.57	85.85			
Total PAH	9720	9723	9065	9502	9798	9860	8542	9458.57	485.03			
Total BaP											96.06	
PCP	2660	2810	2610	2410	2520	2350	2020	2482.86	255.98			
Nutrients, mg/kg												
TOC	27500	25000	29500	24000	27600	28000	18300	25700	3757.66			
TKN	362	511	415	460	404	331	439	417.43	60.22			
TP	456	457	412	490	392	529	469	457.86	45.94			
%Moisture	25.00	25.00	23.00	24.00	23.00	23.00	25.00	24.00	1.00			

Sample Day 140	Contaminant Concentrations, mg/kg, and Physical Analysis											
24-Nov-98												
LTU 2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	286	122	<120	<120	<120	**114**	**105**	156.75	86.45			
ACENAY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
ACENAP	699	704	648	671	716	709	711	694.00	25.06			
FLUORE	751	779	715	757	822	790	807	774.43	36.45			
PHENAN	2740	2890	2710	2750	3020	2920	2990	2860.00	126.49			
ANTRAC	1000	1310	1130	1350	1620	1360	1530	1328.57	213.96			
FLANTHE	1460	1560	1470	1600	1590	1520	1530	1532.86	54.69			
PYRENE	1010	1100	1030	1040	1140	1120	1090	1075.71	49.28			
CHRYSE	261	289	269	280	296	293	288	282.29	13.01	0.001	0.28	0.01
BAANTHR	233	245	226	241	257	250	252	243.43	10.97	0.1	24.34	1.10
BBFLANT	**71**	**79**	**78**	**75**	**89**	**85**	**84**	80.14	6.23	0.1	8.01	0.62
BKFLANT	**79**	**72**	**79**	**90**	**78**	**87**	**86**	81.57	6.29	0.01	0.82	0.06
BAPYRE	**59**	**58**	**59**	**61**	**63**	**65**	**60**	60.71	2.50	1	60.71	2.50
I123PYR	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	0.1	0.00	0.00
DBAHANT	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
2MeNAPH	193	**66**	<120	**29**	**70**	**87**	**97**	90.33	55.43			
Total PAH	8842	9274	8414	8944	9761	9400	9630	9180.71	475.04			
Total BaP											94.17	
PCP	2450	2550	2260	2450	2510	2260	2220	2385.71	135.26			
Nutrients, mg/kg												
TOC	28900	28000	29500	19900	30700	19900	21300	25457.14	4851.07			
TKN	401	442	569	445	498	389	454	456.86	61.05			
TP	451	443	421	455	451	467	459	449.57	14.64			
% Moisture	22	23	24	25	23	23	23	23.29	0.95			

Sample Day 154	Contaminant Concentrations, mg/kg, and Physical Analysis											
9-Dec-98												
LTU 1												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	**32**	**25**	<120	**26**	338	<120	262	136.60	151.59			
ACENAY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
ACENAP	707	686	745	851	776	858	781	772.00	65.93			
FLUORE	710	628	785	791	851	909	869	791.86	97.27			
PHENAN	2400	2140	2690	2600	3040	3270	3000	2734.29	394.96			
ANTRAC	1640	942	1300	1210	1230	1350	1490	1308.86	221.67			
FLANTHE	1560	1510	1560	1700	1670	1690	1610	1614.29	74.13			
PYRENE	1100	981	1040	1160	1150	1190	1020	1091.57	79.44			
CHRYSE	295	279	278	308	313	308	280	294.43	15.44	0.001	0.29	0.02
BAANTHR	255	230	241	265	270	268	243	253.14	15.46	0.1	25.31	1.55
BBFLANT	**86**	**85**	**91**	**92**	**94**	**91**	**90**	89.86	3.24	0.1	8.99	0.32
BKFLANT	**97**	**78**	**80**	**90**	**85**	**94**	**75**	85.57	8.38	0.01	0.86	0.08
BAPYRE	**67**	**61**	**64**	**65**	**70**	**69**	**60**	65.14	3.80	1	65.14	3.80
I123PYR	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	0.1	0.00	0.00
DBAHANT	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
2MeNAPH	**41**	**66**	**24**	**34**	177	**37**	174	79.00	67.15			
Total PAH	8990	7711	8898	9192	10064	10134	9954	9277.57	865.81			
Total BaP											100.59	
PCP	2440	2370	2370	2880	2460	3050	2160	2532.86	314.628			
Nutrients, mg/kg												
TOC	22000	29000	28800	30800	31200	32000	27800	28800	3348.63			
TKN	497	622	669	590	595	570	499	577.4	62.6			
TP	643	659	691	582	516	608	533	604.6	65.1			
% Moisture	28.2	27.5	27.8	26.6	28.2	26.6	23.5	26.91	1.65			

Sample Day 154	Contaminant Concentrations, mg/kg, and Physical Analysis											
9-Dec-98												
LTU 2												
Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	<120	145	<120	<120	**43**	**38**	**28**	63.50	54.69			
ACENAY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
ACENAP	574	747	654	771	728	690	807	710.14	78.37			
FLUORE	378	764	735	810	899	714	805	729.29	166.29			
PHENAN	1300	2650	2480	3020	2740	2650	2720	2508.57	556.97			
ANTRAC	884	1120	1180	1220	3180	1290	1010	1412.00	791.31			
FLANTHE	1560	1690	1530	1800	1610	1700	1620	1644.29	92.53			
PYRENE	1040	1110	1050	1200	1130	1070	1130	1104.29	55.93			
CHRYSE	283	301	279	319	297	284	299	294.57	13.85	0.001	0.29	0.01
BAANTHR	241	265	244	280	249	250	255	254.86	13.56	0.1	25.49	1.36
BBFLANT	**87**	**86**	**81**	**93**	**83**	**87**	**84**	85.86	3.85	0.1	8.59	0.38
BKFLANT	**72**	**88**	**75**	**106**	**86**	**91**	**95**	87.57	11.62	0.01	0.88	0.12
BAPYRE	**55**	**64**	**57**	**66**	**60**	**63**	**64**	61.29	4.07	1	61.29	4.07
I123PYR	<120	<120	<120	**26**	<120	<120	<120	26.00	0.00	0.1	2.60	0.00
DBAHANT	<120	<120	<120	<120	<120	<120	<120	0.00	0.00	1	0.00	0.00
B-GHI-PY	<120	<120	<120	<120	<120	<120	<120	0.00	0.00			
2MeNAPH	**27**	143	<120	**29**	**75**	**54**	**78**	67.67	42.83			
Total PAH	6501	9173	8365	9740	11180	8981	8995	8990.71	1412.91			
Total BaP											99.13	
PCP	1960	2690	2200	2630	2380	2630	2410	2414.29	265.38			
Nutrients, mg/kg												
TOC	29900	28600	25200	27800	29800	26500	26600	27771.4	1776.43			
TKN	456	544	612	623	617	863	667	626	125.0			
TP	627	656	620	530	579	587	650	607	44.6			
% Moisture	26.6	23.5		23.5	23.5	24.7	23.5	24.22	1.26			

Sample Day 168
21-Dec-98
LTU1

Contaminant Concentrations, mg/kg

Replicate	1	2	3	4	5	6	7	avg	Stdev	BaP CF	BaP Equiv	BaP Stdev
PAH												
NAPHTH	35.9	<13	63.3	40.4	11	339	63.1	92.12	122.51			
ACENAY	9	8.1	11	11	9	13.1	14.2	10.77	2.26			
ACENAP	693	569	876	821	728	742	819	749.71	101.85			
FLUORE	749	581	978	846	769	819	882	803.43	124.05			
PHENAN	2780	2170	3300	2720	2770	2860	2690	2755.71	330.80			
ANTRAC	1070	852	1590	1780	1140	1233	1490	1307.86	325.03			
FLANTHE	1560	1410	1690	1650	1650	1600	1640	1600.00	93.46			
PYRENE	923	827	1090	1110	1000	946	1040	990.71	100.07			
CHRYSE	261	230	277	263	272	253	272	261.14	15.95	0.001	0.26	0.02
BAANTHR	219	191	250	238	230	218	230	225.14	18.64	0.1	22.51	1.86
BBFLANT	113	91.9	99	111	94.6	84.9	81.9	96.61	11.98	0.1	9.66	1.20
BKFLANT	86.5	84.8	85.8	79.2	82.7	85	89.7	84.81	3.26	0.01	0.85	0.03
BAPYRE	71.9	63.3	67.7	69.2	61.4	59.6	59.4	64.64	4.97	1	64.64	4.97
I123PYR	31.6	14.3	25.6	29	22.1	23.4	22.3	24.04	5.57	0.1	2.40	0.56
DBAHANT	<13	<13	<11	<13	<12	<12	<12	0.00	0.00	1	0.00	0.00
B-GHI-PY	24.4	11	21	22.6	18	18.4	17.4	18.97	4.36			
2MeNAPH	55.5	14.4	96.7	69.8	25.2	173	104	76.94	53.93			
Total PAH	8682.8	7117.8	10521.1	9860.2	8883	9466.4	9515	9149.47	1082.98			
Total BaP											100.33	
PCP	2460	2120	2490	2320	2240	2270	2480	2340	141.539			

Sample Day 168
21-Dec-98
LTU2

Contaminant Concentrations, mg/kg

Replicate	1	2	3	4	5	6	7	avg	stdev	BaP CF	BaP equiv	BaP Stdev
PAH												
NAPHTH	10	33.9	12.4	21.5	6.7	15.1	22.8	17.49	9.29			
ACENAY	9.8	12	11	8	8.8	12	11	10.37	1.55			
ACENAP	662	719	669	662	726	688	737	694.71	32.15			
FLUORE	588	674	722	739	787	680	762	707.43	66.65			
PHENAN	1980	2210	2430	2650	2790	2370	2630	2487.14	280.52			
ANTRAC	1050	1210	1270	1430	1080	1550	1040	1232.86	198.05			
FLANTHE	1540	1680	1550	1620	1790	1680	1690	1650.00	87.55			
PYRENE	946	1020	995	974	1100	1010	1030	1010.71	48.67			
CHRYSE	260	282	261	261	299	274	280	273.86	14.48	0.001	0.27	0.01
BAANTHR	220	236	228	235	256	239	232	235.14	11.11	0.1	23.51	1.11
BBFLANT	60.1	89.1	81.2	76.4	84.1	88.1	92.3	81.61	10.87	0.1	8.16	1.09
BKFLANT	66	76.6	77.4	81	69	73.8	75.6	74.20	5.14	0.01	0.74	0.05
BAPYRE	48.7	58	53.7	54.9	53.7	57.9	53.6	54.36	5.14	1	54.36	5.14
I123PYR	17.1	23.6	21.3	21.4	19.9	23.8	24.4	21.64	2.58	0.1	2.16	0.26
DBAHANT	<12	<12	<12	<12	<12	<12	<12	0.00	0.00	1	0.00	0.00
B-GHI-PY	13.2	18.2	16.7	16.2	15	16.8	17.1	16.17	1.63			
2MeNAPH	20.6	53.2	19.4	40.8	15.8	24.8	43.4	31.14	14.45			
Total PAH	7486.5	8395.6	8418.1	8891.2	9101	8803.3	8746.2	8548.84	531.50			
Total BaP											89.21	
PCP	2320	2580	2300	2380	2650	2400	2340	2424.29	136.12			

Sample Day 168 21-Dec-98 LTU 1 Replicate	**Physical Analysis**								
	1	2	3	4	5	6	7	avg	stdev
Nutrients, mg/kg									
TOC	18100	17800	17600	18900	25300	20700	15400	19114.3	3153.53
TKN	1557	2598	1309	910	1213	1218	1140	1420.71	553.91
TP	538	755	509	504	541	702	627	596.57	99.91
PSD									
% Gravel	0	0	0	0	0	0	0	0	
% Sand	55.17	54.5	51.78	56.72	49.92	56.36	47.69	53.16	3.44
% Fines	44.83	45.5	48.22	43.28	50.08	43.64	52.31	46.84	3.44
Atterburg Limits									
liquid limit	23	24	22	23	25	24	25	23.71	1.11
plastic limit	17	19	18	18	19	18	21	18.57	1.27
plasticity index	6	5	4	5	6	6	4	5.14	0.90
soil type	silt	silt	silt	silt	silt	silt	silt		
% Moisture	26.5	27.6	25.5	26.1	25.4	24.3	26.1	25.93	1.02
pH	7.64	7.75	7.76	7.72	7.76	7.72	7.92	7.75	0.08

Sample Day 168 21-Dec-98 LTU 2 Replicate	**Physical Analysis**								
	1	2	3	4	5	6	7	avg	stdev
Nutrients, mg/kg									
TOC	22100	23200	24000	22500	22200	21100	21000	22300	1073.93
TKN	1388	1464	1305	1489	1344	1307	1473	1395.71	79.76
TP	557	565	521	561	560	522	518	543.43	21.76
PSD									
% Gravel	0	0	0	0	0	0	0	0	
% Sand	44.6	35.24	44.69	60.25	36.94	54.63	44.24	45.80	8.96
% Fines	55.4	64.76	55.31	39.75	63.06	45.37	55.76	54.20	8.96
Atterburg Limits									
liquid limit	23	23	23	23	21	23	24	22.86	0.90
plastic limit	18	18	19	19	18	20	19	18.71	0.76
plasticity index	5	5	4	4	3	3	5	4.14	0.90
soil type	silt	silt	silt	silt	silt	silt	silt		
% Moisture	24	24.8	24.8	24.3	23.4	23.7	23.6	24.09	0.57
pH	7.96	7.97	7.75	7.76	7.66	7.89	7.83	7.83	0.12

Appendix C
Leachability Data

Leachability Test

Replicate

SPLP	Concentration, mg/L 1	2	3	4	5	avg	stdev
PCP	35.3	33.2	30.4	34.7	38.6	34.44	3.00
NAPHTH	5.3	5.24	6.34	6.22	5.91	5.80	0.51
SBLT							
PCP						avg	stdev
1	98.7	99.9	97.8	105	107	101.68	4.08
2	63.3	61.5	60.4	58.5	59.8	60.70	1.81
3	36.9	36.6	36.0	34.5	34.1	35.62	1.26
4	24.4	27.4	21.8	27.6	29.6	26.16	3.06
NAPHTH							
1	6.65	6.59	6.44	6.03	6.09	6.36	0.29
2	**3.73**	**3.77**	**4.03**	**3.36**	**3.63**	3.70	0.24
3	**4.21**	**4.41**	**4.36**	**3.90**	**3.84**	4.14	0.26
4	**4.27**	**4.33**	**4.04**	**4.36**	**4.32**	4.26	0.13

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14. ABSTRACT
A pilot-scale study of traditional landfarming techniques was conducted to evaluate the treatment requirements directed in the Comprehensive Environmental Remediation Compensation and Liability Act (CERCLA) Record of Decision (ROD) from EPA Region 6 for this site. The study was conducted to: (a) determine if treatment goals specified in the ROD were achievable for site soils (5-ppm benzo(a)pyrene [BaP] equivalents and 3-ppm pentachlorophenol [PCP]; (b) evaluate contaminant degradation kinetics; and (c) evaluate leaching potential of treated soil.

Initial soil characterization (physical, chemical, biological) indicated a clay/silt soil (based on Atterberg limits and particle size distribution) with high contamination (polycyclic aromatic hydrocarbons [PAH] ≅ 13,000 ppm, PCP ≅ 775 ppm, BaP eq ≅ 105 ppm), and an indigenous biological community (approximately 10^7 cells/g as determined by ester linked polar lipid fatty acid (PLFA) analysis). Intermittently scheduled experimental analysis included contaminant concentration, nutrient concentration, pH, moisture, in situ respiration, and microbial community/biomass analysis.

(continued)

15. SUBJECT TERMS
Bioremediation, CERCLA Remediation, Creosote, Landfarming, PAH, PCP, Pentachlorophenol, Polycyclic aromatic hydrocarbons, Super fund site, Wood treatment facility

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
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14. ABSTRACT (Concluded)

The pilot-scale site consisted of a modified RCRA secondary containment system that contained two, 3-cu yd land-treatment units (LTUs) designed to simulate field conditions. LTU 1 was cultivated on an oxygen-dependent basis. LTU 2 was cultivated on a fixed schedule. Soil moisture was maintained between 50% and 80% of field moisture capacity. A novel in situ respiration analysis technique was developed using a custom fabricated dry well and an in-line O_2, CO_2, CH_4 analyzer to evaluate aerobic biological activity. Before and after treatment leachability analyses were conducted using the Sequential Batch Leachate Test (SBLT) and the Synthetic Precipitate Leaching Procedure (SPLP) to evaluate the groundwater implications of the underlying aquifer when the treated material is placed back onsite.

Using a zero-order degradation model, contaminant analysis indicated that BaP treatement goals could be met in 9.6 years for LTU 1 and 2.7 years for LTU 2. PCP was not degraded appreciably in either LTU. Respiration analysis, coupled with statistically significant reduction in heavy PAHs (4-, 5-, and 6-ring), demonstrated significant biological activity even at the unusually high contaminant concentrations observed. PLFA analysis showed continuous increase in biomass and divergence of community composition between LTU 1 and LTU 2. LTU 2 showed an increase in the relative percentage of gram negative bacteria. Pre- and postleachability analysis indicates that the treated material will not serve as a source of groundwater contamination if placed back onsite.